SCIENCE FOR EVERYONE

EKATERINA RADKEVICH

EARTH, SWEET EARTH

MIR

SCIENCE FOR EVERYONE

The book is based on the author's impressions of her numerous expeditions in the many countries. It is a fascinating narrative rather than a mere record of facts irrespective of how scientifically valid they can be. The book is bound to be appreciated as a piece of absorbing reading by anyone who cares to increase the scope of his or her competence about our sweet home of a planet that must be saved from destruction at all costs.

Ekaterina Radkevich, Corresponding Member of the USSR Academy of Sciences, is one of the most distinguished geologists whose works are well known in her own country and in many other parts of the world. The overwhelming success of her publications is chiefly due to her indefatigable practical activity in the USSR and elsewhere and her unflagging interest in theoretical research which she has been conducting for quite some time at the Institute of Geological Studies in the Far East (Vladivostok).

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for Everyone

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How I Became a Geologist

(In lieu of preface)

How and why did I become a geologist? Partly it was quite by chance. I came to Leningrad to be matriculated at the ethnographic department of the geological faculty with the aim of specializing in Uzbek folklore only to suddenly change my mind and apply for admission at the Mining Institute. What attracted me was the romantic aspect of my future profession. The very name of the geological survey faculty drew me toward it like a magnet. Suffice it was to imagine the wanderings into remote and unknown lands. How interesting it all was! What also fascinated me was the outside view of the building—the moss-covered walls, the classical columns, and the busy students, most of whom were boys still in their teens hurrying to their lectures.

Thus I had always thought that my choice was no more than haphazard as is often the case with girls of eighteen who are remarkable for their lack of consistency when it comes to determine their own place in life. But actually, the way I look at it now, my choice of profession was not accidental at

all. The idea that there had been raison d'être about it came to me only recently when I was in Tashkent University on the invitation of the biological faculty to commemorate the centenary of my mother's birthday. My mother, Olga N. Radkevich, was a biologist and one of the first lecturers of that university, and undoubtedly it was she who had predetermined my interest in geology, which had remained dormant prior to its spontaneous eruption.

My mother—a student of higher courses for women—was in her time very much engrossed in geology herself. She was one of those students who listened to the brilliant lectures delivered by A. Fersman, who was wont to tell his audiences of the beauty of minerals, and inspired the undergraduates with his temperamental disquisition of the remarkable panorama of mineral formation. Another great scientist who used to give lectures there was V. Vernadsky. It was by accident that my mother left the field of geology: she did not have enough strength to blow into the soldering tube and smelt the metallic globule from the minerals under investigation. She became a botanist, though her interest in geology had never slackened.

Together with her classes at the Central Asian University she taught natural sciences at the school where I studied. And it was precisely here that her attachment

to geology manifested itself. She would take us on excursions to the foothills in the suburban parts of Tashkent, where we would assiduously chop off the specimens of rocks with the help of a geological hammer and discuss with fervour what probably lay behind the development of that particular region. Thus, for instance, pebble-beds had been formed in the littoral zones. In the upper layers they were replaced by sandstones that had emerged from the sand of the coastal zone of the sea or ocean, and still higher by layers of clay. Apparently, at the time of their deposition the sea had spread further upon the land, the shore had retreated, and what was already being deposited on the sea floor included light fine clay particles.

At school I gave talks on volcanoes and earthquakes, and what I particularly liked was the Pacific volcanic ring which I drew on maps with great effort. Well, it goes without saying that I could not have possibly foreseen that I would become a geologist and would be doing my research precisely within the domain of the Pacific region, and would even climb up to the highest volcanoes and find myself close to them at the time of their eruptions.

I avidly read the thick books by Heimeer, Mushketov, Hauge, and Vernadsky that were available in our home library. Everything seemed captivating, and yet

the idea that I should become a geologist had never occurred to me.

And here I am—a geologist who has been working in this branch of science for over 55 years, who has done quite a lot of travelling in many countries, who has become acquainted with a large number of ore deposits, gone down to the deepest mines and up to the highest mountains. Years pass, but my love for geology does not seem to wane, and there has not been an hour which I have been sorry for the choice of profession that I made in my youth.

From the very first days interesting discoveries were awaiting me at the Mining Institute. What especially drew me to it was the geological museum. The exhibitions included collections of beautiful shells which help geologists determine the time that beds of rocks were formed and distinguish the ancient varieties from those that are younger. And how coruscant the minerals on display were! They represented bright and scintillating ores of lead, zinc, and copper. I was enthralled by the sight of a huge plate of native copper which the Ural miners had figuratively called 'the bear's skin'. It hung on the wall of the Museum. Looking at it one could readily imagine how rich the copper mines of the Urals were at the beginning of the workings. Everything fascinated the eye—precious stones, specimens of gold, and meandering

complicated forms of native silver! Of course quite a bit of time had passed before I learned the names of all those minerals, their properties, and could recognize them during the exploration activities.

But the first expeditions, though not devoid of difficulties, were very interesting indeed. There were not many girl students at the institute, and the attitude to them on the part of the old teachers was rather sceptical. When, after hearing all the wonderful stories about the field expeditions that were told by our teacher of geology Pavel Alexandrovich Gryushe, I imploringly said:

"Oh, take me with you, please!"

He said,

"Not girls!"

"But why?"

"They are not fit to work in the conditions of Central Asia."

"Not in my case! I was brought up in those parts and can even speak Uzbek."

Strange as it might seem, this was exactly what determined my fate. I was made a member of the expedition ... as an interpreter. This was followed by the expedition to the Pamir mountains, where I was already a caravan worker. However, in spite of all this, I did find the time to do geology.

Things are quite different with the work of women in the field of geological science today. In geological institutes and expe-

ditions, particularly in laboratory groups which deal with the processing and analysis of the collected materials, a considerable part of the work, sometimes more than half of it, is done by women.

Years of strenuous studies are behind. And now the question crops up again. What profession to choose? It occurs that geology is not a single science but a whole multitude of allied sciences, a complex of subjects dealing with the Earth. It would of course be interesting to become a paleontologist and do the historical geology, reconstructing with the help of minute and delicate shells, the remote past of our planet and the time the rocks were formed .... But isn't it still more interesting to be a mineralogist, or a geochemist, and work with the beautiful minerals which we invariably admire at the museums. How resplendent they are in the mine workings and in the light of the miners' lamps! What is also attractive is the technical profession proper—the exploration of deposits. This is precisely where you can really show how proficient you are as a mining engineer and be most useful to your country. It is more interesting to be a geophysicist and study the innermost structure of the Earth or the location of the hidden ore deposits on the deep levels.

Thus, by the time we graduated from the Institute we knew for certain that geology

was a branch of science with many plans: on the one hand it was historical and, on the other. it belonged to natural sciences, since it was connected with chemistry (mineralogy, geochemistry), with physics, and mathematics (geophysics, crystallography), as well as cosmology (the origin of planets). and lastly with mining engineering. I became a survey-engineer and all my life have studied the ores.

...But the mountains still exert their magnetic influence upon me. Ever since I was a child I have loved them, presumably from the days when I was a little girl of five and accompanied my mother in her botanical excursions along the slopes of the Caucasian mountains. On her back mother carried a file and in her hands she held a little dagger for digging out the plants. And later, when we moved to Central Asia, the mountains lured me with their deceptive propinquity. What one wanted to do was to turn up to them, climb up the steep slopes without a respite and reach the snow caps.

Years passed. I used to embark on my individual excursions into the mountains, collected red little stones—the silver mica schists, and in a rivulet would find variegated pebbles of granite having the size of pigeon's eggs. Those were my treasures. Later I became fond of rock-climbing... got up the rocks much better than many

boys. I was not afraid of either height or dizziness, which helped me in my future highly complicated itineraries in the Pamirs. So it was not by chance that I became a geologist. My affinity with the mountains had led me to my profession since early childhood.

It is not easy to be a geologist. One must be not only absorbed in his work, but also have enough patience and perseverance in overcoming the impediments and difficulties, and be unflagging in the pursuance of the aim, no matter how inaccessible it might be. I wouldn's say that I possessed all these qualities, but I do try to strengthen them, which helps me in my seventies not to be lagging too far behind my young colleagues.

Thus, since my days of childhood I have got in touch with geology. Moreover, I think that you, my dear readers, presumably know more about geology than it might seem at first. I heard over the television very interesting and comprehensive answers at the quizz-contest of the young geologists. And, indeed, they were the boys and girls who participate in the work of the geological clubs at the Moscow University and the Moscow Institute of Geological Survey. But I think that none of you can feel indifferent to the beauty of stones. You see them in the facing of the Metro stations and the walls of the Palaces of

Culture, to say nothing of the charm of precious and semiprecious stones, which one can see in shop-windows and as ornaments in everyday life.

Do not remain without interest or concern as regards the stones, since they can tell you much about the past of our planet and about the geological history of those places where you live....

The team of the Geological Institute in Primorye (the Far East) where I work is studying the tin deposits. The interest this subject presents can hardly be overrated. It is necessary that the origin of tin ores and the regularities of their distribution should be specified to conduct the buests more effectively. The help is required by the geologists working in industry, among whom there are post-graduates doing their studies by correspondence. On the other hand, we receive no little help from the schoolchildren, who studying at the school of young geologists, which had been organized by Anatolii M. and Dina K. Kokorins—members of our institute staff.

I left for the ore district to give advice to my colleagues and post-graduates, working in the mines and in expeditions of the Ministry of Geology, and got stuck there by accident: the planes did not fly because of bad weather. It was really a pity; but I tried to comfort myself by joining the

young people in their itineraries, and telling them something about geology, bringing back to mind my school-day geological excursions and infatuations for this kind of work. But when the Sun went down we would be sitting by the campfire, looking into the boundless starry sky and singing.

But why don't the planes fly?

We are planning to start early tomorrow to go en route and look for ores. And why shouldn't we find them? We already have some encouraging information that they can be found in one of the valleys.

Try to imagine that you are coming along with us. We go up the stream and our eyes are focussed on the boulders in its channel. Something white has just glittered. It must be quartz. We picked it up, broke it with the hammer, and saw that it was quartz itself. Now, it is common knowledge that in quartz veins we can find various useful minerals and ores. Here is one more boulder. Its size is already greater. We must be approaching the place whence the fragments of a quartz vein fell off. Still further, up along the stream, quartz fragments are not to be found any more, we must have lost their 'trace' somewhere.

We are on our way back, and again we look into the valley slopes. We did miss them after all! It is exactly here along the lateral creek valley that pieces of quartz

stand out. We all get enthusiastic. My young colleagues start to hammer the stones one by one, hoping to find if not gold, then at least pyrite, looking like gold Soon, however, we find pieces of not only quartz, but also of ore covered with a crust of brown iron ore, which had been formed during the oxidation of ferruginous minerals. The farther we go—the greater they become in number. Now, we have almost reached our goal. All the hammers in unison hammered their way through the places of those stones that interested us until the ore vein made itself apparent to us.

The day has not been wasted! We plot the discovered ore dot on the map, carefully put together the specimens, write labels for them, wrap them up in special kind of paper and put them into our little bags. Care should be taken not to mix up anything. Later we shall study these samples and undoubtedly find something very interesting in them.

Meanwhile people in the camp are busy of analyzing the materials, making entries into the diaries and setting the collected samples into order. Dina Kokorina is studying the ore sections under the microscope and lets the young people look at them too. What we see before our eyes is the enchanting beauty of minerals in the polarized light of the microscope. The one that is particularly fascinating among them is

cassiterite—the tin-stone the ores of which we have been studying for many years. Under the microscope 'our' cassiterite, which is found in the ores in the form of black or brownish crystals, is playing all the colours of the rainbow: red, green, orange, and yellow within the minutest sections. 'I shall be a mineralogist by all means,' says the girl Svetlana. 'And as for me I shall do the survey work,' remarks Pavel.

When the sun sets behind the horizon, we sit at the campfire with our thoughts far away with the stars that never fail to lose their attraction. 'How I would like to fly to the stars,' we hear some of our young members saying with a sigh. 'Oh, but you won't be able to do that even if you fly with the velocity of light,' comes the comment from someone else. One cannot but wonder at how much these young people know! I tell them how unfathomable our universe is, in which our Earth is but a little particle.

I know that many of the participants of these expeditions have already become geologists. These young people may also join their ranks in the future. It is with them—the dreamers, the ones that may become the discoverers of the Earth's mysteries and the secrets of outer space—and those of the same age with them and perhaps with the grown-ups who have

still retained the children's curiosity, that I am trying to share my experience, that I have not been able to tell my listeners at the campfire and answer the questions that crop up with the inquisitive young people, the questions which keep pouring just as the children's verse that is used for remembering the school grammar: 'Where, where to, when, whence, how, why, and what for?'

I will tell my readers about the Universe and its origin, though there will be more to say about our own Earth, the processes that take place on it, the formation of ores and the methods of their quests. It is quite natural that the answers will by far be not exhaustive. As far as the most important questions are concerned, there exist different points of view; the same facts find diverse interpretations with the geologists. However, there do exist irrefutable principles of geological science, which are made use of during the explorations and which are verified in practice. As regards the hypotheses, their number in any science is very great indeed. The confrontation of different opinions is exactly what brings us closer to the truth, which always leaves room for further explorations.

Part 1

The Earth in the Universe

Chapter 1

The Earth as a Cosmic Body

The Earth is man's home. Our knowledge of the Earth, its forms, size, structure, and position among the other planets is all the time on the increase. The achievements in scientific studies provide us with many new facts. Today we know that the Earth is no more than an infinitesimal particle in the universe, one of the tiny planets of the small star called the Sun, which enters into the Galaxy, that is a great accumulation of some 100 billion stars. But there are other galaxies brought together into a larger stellar association—the metagalaxy.

The most tangible successes in astronomy owing to the improvement of the quality of telescopes, the use of astrophotography, exact physical methods of research, such as spectral, roentgenochemical, radiochemical and other analyses, help us to penetrate into the secrets of the universe ever more profoundly.

Sidereal sky has never left man indifferent to itself. Even nowadays when we sometimes happen to escape from the cap-

tivity of urban civilization, we, just as our remote ancestors, who were wont to sit at their campfires for hours on end (they must not have been pressed for time for that purpose), watch the miraculously mysterious sky above us. Since time immemorial people had undoubtedly noticed constellations—those highly intricate concentrations of stars, whereas the Sun, giving us light, heat, and life was deified. Even our own ancestors—the Slavs—only a little over one thousand years ago worshipped the Sun, or Yarila, as they called it in their language. The stars and particularly the planets wandering in the sky (it didn't take people much time to distinguish them among the immobile stars that do not change their relative position) were attributed the qualities pertinent to witchcraft. Their localities gave rise to fortune-telling, and the prophecy of events as well as fates of people.

The observations of heavenly bodies preconditioned the advent of not only superstitions but also of practical knowledge. In the countries of ancient civilizations (Egypt, Mesopotamia, and probably, China) it was as early as the third millenium B.C. that the priests had been watching the firmament. They used to compile calendars and accurately determined the number of days in a year, while months were singled out according to the phases of the Moon.

The initial lunar calendars were later succeeded by the solar ones.

Calendars guided people as far as the periods of field works were concerned, and the Egyptians used them to know exactly when the Nile River would be overflowing again and thus cover the vast valley with its fertile silt. Observations of the position of stars and planets were proved to be also helpful to seafarers and travellers. Hence, rudimentary practical knowledge in astronomy had already played an important role since the very inception of ancient civilizations.

But the general concepts pertaining to the situation of the sky in respect of the Earth have been developing with all the nations in about the same way. The Earth is the centre of the universe, the Sun exists to give it heat, while the Moon and the stars illumine it at night. There could have been no other explanation provided by the human being whose egocentric ideas had always made him feel in the centre of everything that existed. The very same geocentric concepts (the Earth as the centre of the universe) entered into the basic precepts of religions, and strange as it may seem, have continued to function as such until now.

The generalization of practical knowledge concerning sidereal sky formed the basis of astronomical studies in the ancient times,

its scientific validity was irrefutable. Maps of sidereal sky were compiled, and statements though naive but sometimes on the whole correct were made as regards the position of the Earth in space. The beginning of the general theoretical concepts about the world goes back to the materialistic philosophers of Ancient Greece, while the mathematicians of those remote days had already been not far away from defining the forms of the Earth. Thus, the followers of Pythagoras thought that the Earth was a globe. This helped them to have a better understanding of the nature of solar and lunar eclipses. Some scientists, however, asserted that the Earth together with the Moon, the Sun and other planets rotated in spheres round a certain fiery centre. This was already a digression from the geocentric assumptions according to which the Earth was the centre of the universe.

The one who even more definitely spoke against the geocentric concepts was the scientist from Alexandria known as Aristarchus of Samos (310-250 B.C.). He was trying to prove that not only the Sun was moving round the Earth, but that the Earth was rotating round the Sun. This scientist is called 'the Copernicus of the ancient world'.

Again in Alexandria—the greatest scientific and cultural centre of Hellenism—there lived some time later an eminent man of

science Claudius Ptolemy (the second century B.C.), who was known for his major works on astronomy and who returned to geocentric notions. The high authority of this scientist who left on his demise voluminous treatises containing the generalization of astronomical knowledge of those days made the science 'come back' to geocentrism. It should be mentioned, however, that Ptolemy himself did not wholly reject the possibility of heliocentric assumptions, though for practical purposes he gave preference to geocentrism. The astronomical charts compiled by him have done good service to the travellers for many a century. This is where we have a comparatively frequent occurrence in science when, in spite of the erroneousness of theoretical conclusions, the facts and generalizations of empirical material that are adduced to substantiate such inferences play a significant role in theory and practice. The geocentric concept advanced by Ptolemy has been consolidated for thousands of years mainly because it was in compliance with the teachings of Church.

It was only in the 16th century A.D. that the outstanding Polish scientist Nicolaus Copernicus proclaimed to the world that it was not the Sun that 'moved' round the Earth, but the Earth that rotated round the Sun. This was how the modern heliocentric scientific concepts were founded.

It is assumed that Copernicus was aware of the ideas propounded by the ancients including Aristarchus of Samos.

The thoughts advanced by Copernicus could not pave the way for themselves for a long time since they contradicted the ecclesiastic views on the creation of the world. Those who defended the new scientific concepts were burnt at stake, and excommunicated. What will remain indelible on the memory of mankind is the similar kind of murder of Giordano Bruno (1548-1600), the scientist who became a martyr for spreading the ideas of Copernicus, and for proclaiming that we lived in only one of the many worlds. We pay homage to the memory of the great scholar Galileo Galilei (1564-1642) who was the first to seen the satellites of Jupiter with the help of the self-made telescope and whom later the inquisitors forced to renounce his wonderful observations and scientific conclusions.

After the German astronomer Johannes Kepler (1571-1630) discovered the laws of the movement of planets and estimated their orbits, and when Isaac Newton's (1662-1727) law of universal gravitation was made known to the scientific world, Copernicus's ideas had received a new life. It was since then that the fundamental principles of scientific planetology and cosmology had been consolidated. And it is particularly today—in the age of space

research—that the knowledge about the universe and heavenly bodies is flourishing most successfully.

The universe, or the whole world, can be regarded as a combination of two types of the concentration of matter: the rarefied outer space (one atom per cubic centimetre!) and the superdense concentrations of matter in the stars. The latter are situated at enormous distances from each other, the mileage exceeding their diameter millions of times. They are grouped into systems, or galaxies, while the latter give rise to still greater associations called the metagalaxy of stars and nebulae. The galaxies are of various forms. They can be found to be either elongated, lenticular, or globular.

Our own Galaxy is the one that has been studied most thoroughly. It is characterized by a spiral-like flattened form with ramifications, or arms. A large number of stars are concentrated in the axial zone which is close to the symmetry plane of the Galaxy. And it is precisely there that we have the Milky Way, the very well known conglomeration of an infinite number of stars. Their number in our Galaxy is about 100 billion.

The stars are not of the same value as far as their size, luminosity, and 'age' are concerned. Among them there are supergiants, giants, stars of medium dimen-

sions and those are so little that they are called dwarfs.

In the course of their development stars cover various stages. Having emerged as a result of the thickening of matter and its heating, the stars reach ultra-high temperatures. The processes that take place within them included thermonuclear reactions with the transformation of hydrogen into helium, which lead to the further heating, burning, and radiation of energy and matter into space.

In due course, stars lose their light, and perhaps many of those twinkling stars that we see in the sky now faded a long time ago and what we see is only their far-off light. The other stars, however, are only coming into being as the new explosions and contraction of matter take place. These new-born stars are called new or supernova.

According to their luminosity (brightness) and stages of development stars are classified into the following classes: O-B-A-F-G-K-M. To memorize this series more easily people have composed special phrases in which each consecutive word begins with the letter of the stellar class. In English it sounds very nice: 'Oh, Be A Fine Girl, Kiss Me!'

In accordance with the change in luminosity the colour of stars varies from blue to white, yellow, and red. The most high-

temperature stars are the supergiants of groups O-B. Stars of group O are characterized by the glow in the ultraviolet part of the spectrum, the manifestation of ionization of some elements whose atoms are split into ions. The stars of the following groups have a lower temperature on the surface: B—from 25 000 to 12 000°; A—from 11 500 to 7 700°; F—from 7 600 to 6 100°; G—from 6 000 to 5 000°; K—from 4 900 to 3 700°; M—from 3600 to 2600°.

The composition of stars is more or less similar: hydrogen and helium are predominant in all of them. In due course and as a result of thermonuclear reactions hydrogen transforms into helium. The other elements (there are not less than 60 out of those that are known to us on Earth) comprise in the stellar atmospheres not more than 5%.

Our Sun is a star of no great magnitude. It is a yellow dwarf which refers to group G. Its temperature is approximately 6 000° in the surface layers, and it is 10 billion years old.

The Sun is closer to the periphery of the Galaxy and is situated between the arms of its spiral. From the nearest star, β Centauri, the Sun is very far away. If we tentatively take pinheads for the dimensions of these stars, distance between them on the same scale will be 40 kilometres, for such is the remoteness of stars from each other.

The study of the spectra of far away stars shows that there is a shift of spectral lines in the direction of the long waves of the red part of the spectrum. This is considered to be a feature signifying the remoteness of stars from us. The statement concerning the 'scattering' of galaxies served as the basis for the hypothesis concerning the ever expanding universe. It is assumed that 20 billion years ago there occurred an explosion of superdense concentration of matter, after which clots of it flew apart and formed star worlds. On the other hand, there also exist other hypotheses, as for instance that of the pulsation of the universe with the alternation of compression and expansion that is irregular in its different parts.

Chapter 2
The Planet Earth

The Earth is one of the inner planets of the Solar System, which is situated at a relatively small distance from the Sun. Planets of this kind include Mercury, Venus, the Earth, and Mars—the so-called stone planets, consisting mainly of silicate rocks. The dimensions of the Earth and its distance from the Sun are taken as a unit when compared with the other planets.

The Earth is an ellipsoid that is somewhat flattened at the poles with the equa-

torial radius equal to 6 378 kilometres and the meridian radius measuring 6357 kilometres. The difference in radii is inconsiderable if we compare it with the differences in the Earth's relief (up to 20 kilolmetres) between the oceanic troughs the depth of which exceeds 11 kilometres and the highest mountains that are above 8 kilometres (Mount Everest).

The Earth is the third planet in distance from the Sun. The mean radius of its orbit covers 150 million kilometres. The distance from the Sun is not so near as that of the hot planets—Mercury and Venus—and not so remote as the distance between the cold Mars and the Sun. The Earth receives moderately warm solar rays.

In these conditions there took place a rapid cooling of the Earth's atmosphere, the water vapours gave rise to water, which resulted in the emergence of hydrosphere, or the aqueous mantle of the Earth, which the other planets are deprived of. In its turn the hydrosphere, invigorated by the rays of the Sun, became responsible for the appearance of life, which some time later promoted the enrichment of the Earth's atmosphere with oxygen. With the burgeoning of life biosphere came into existence, followed by the advent of Man-Nature's Last Word. This brought forth the so-called noosphere, or the region of the functioning activity of Man, which also represents

a highly important geological factor. These are many of the consequences resulting from the advantageous position of the Earth in respect of the Sun.

The planet Earth also has some other features that are typical only of itself.

The Earth's axis of rotation is inclined to the surface of its orbit at an angle of 20 degrees. How and why did there appear this inclination and how did it itself influence the distribution of masses in the Earth? This question has still remained unanswerable. In the course of time the inclination of the axis could change depending on the distribution of continental masses. It is assumed that even an insignificant uplift of only the South-American continent would have been enough to alter this inclination. Now in the history of the Earth there have been a great number of such uplifts and submersions of continents. In South America itself gigantic ridges of the Andes rose as high as 5-6 kilometres 10 million years ago. Approximately at the same time there emerged the highest Himalayas.

By using the paleontologists' observations of the accretions of coral zones corresponding to the diurnal and annual fluctuations of temperature in the seas, V. Belousov came to the conclusion that in the Cambrian period (500 million years ago) the day was shorter: it had 20 hours and

not 24, while the Earth rotated at a more rapid rate. 4.5 billion years ago the 24-hour period that we now have on Earth comprised only 2 hours. Presumably, within the period of its formation the Earth that was still not great in volume rotated even faster. What we expect to have in the future, however, is a gradual retardation of the rate of its rotation.

The change of seasons in connection with the rotation of the Earth inclined to its orbit round the Sun causes a rhythmical fall out of various precipitation from waters, as, for instance, the layers of fertile silt in the soils of the Nile River, and micro-laminated varved clays in the regions of recent glaciation. According to the alternation of layers with the coarse- and fine-grained material it becomes possible to estimate the duration of the formation of the mass in exactly the same way as the age of trees is calculated by the lines of growth. In cases like these one must have enough patience.

What is also of no minor importance for geology is the rhythmic phenomena of a wider scope, as, for instance, the orbital rotation of the Sun in the Galaxy with the cycle of about 200 million years. These movements are associated with the periodic renewals of active tectonic processes. The comets that pass in the proximity of the solar system and follow their complicated

paths in the Galaxy, hosts of meteorites and the bursts in the vicinity of the Galaxy of supernovas exert their influence on the Earth too. Various space and planetary phenomena can affect the geological processes and the development of life, thus bringing about the substitution of one kind of organisms for the others. Hence, the Earth, which is generated by space continues to experience the impact of space processes

The extraordinary peculiarity of the Earth, distinguishing it from many other planets of the solar system is that it is a strong magnetic field. The Earth's magnetosphere plays a significant role in 'protecting' the living organisms from the pernicious impact of the corpuscular radiations emitted by the Sun. Perhaps it was precisely the magnetosphere that 'presented' the Earth with a most precious treasure called life and provided it with the required defence.

The existence of terrestrial magnetism is common knowledge and can be verified by looking at a compass needle. It was in the ancient times that compass was invented in China, and for thousands of years it has faithfully served the needs of seafarers and travellers. It also shows the position of the North, though it will be the position of the magnetic rather than geographic pole, which is found to be at

a certain distance away from the magnetic pole. This correction for magnetic declination is always taken into account by the seamen, geologists and all the travellers.

What lies at the bottom of the fabulous activity of the Earth's magnetic field? In a simplified way it is understood that in the core of the Earth and rather eccentrically as regards its centre there exists a magnetic dipole like a magnetic core with two poles of different signs, and this is what precisely determines the position of the magnetic lines of force round the Earth. It has also been established that the North Pole is not stable and its 'trace' has the form of a boiler. At present the pole moves towards North America at the rate of 11 centimetres a year.

The magnetologists prove that changes in the position of the magnetic poles had also taken place in the past. These conclusions are based on the changes in the orientation of magnetic minerals contained in the rocks. Minerals, ferromagnets (e.g. magnetite), and iron filings above the magnet were situated in the rock, melt, or sediment in a way that they were subservient to the lines of force of the Earth's magnetic field, with this kind of arrangement remaining as such for a long time. This is exactly what helps to establish the previous position of the magnetic pole.

The paleomagnetologists have discovered

a remarkable phenomenon. They claim to have a sufficient evidence that in the past the poles used to change their signs. The North Pole would become the South Pole, and the South Pole was wont to become the North Pole, in addition to which the periods of relative stability of the position of the sign of poles covered the period from 0.7 to 1.4 million years.

Other remarkable 'deeds' are attributed to the poles too. The paleomagnetologists assert that in the past there also took place remote and stable dislocations of the poles: for instance, the North Pole was at one time situated in the region of the present-day Australia! What serves as the basis for such conclusions is the same data that concern the change in the orientation of magnetic minerals (it occurs that in masses of different age it is not the same), which is exactly what helps to assume the variation of the position of magnetic paleopoles in different periods of the Earth's history.

These concepts are disputed by some of the researchers. The same data provided by paleomagnetologists are employed for the inference as regards the marked horizontal dislocations of plates of the earth's crust. The proponents of this hypothesis prove that it is not the poles that migrate, but the continents themselves are in a state of movement. In their opinion this

is exactly what brings about the incongruity in the orientation of ancient magnetic minerals and the contemporary position of magnetic lines of force. The problem still awaits its solution.

Another interesting characteristic feature of the Earth is its heat condition. The surface of our planet receives its heat from the Sun, but the heat does not penetrate into it deeper than 200 metres. But, as the depth increases there begins to function another of its sources—the thermal deep-seated flow. It comes from the melted masses, during the radioactive decay and, probably, from the residual reserve of heat, which has been preserved in the deeper regions of the Earth ever since the time of its formation (compression, the attraction of heavy elements to the centre, accompanied by the general heating of the planet).

In any event the Earth's temperature grows as the depth increases. The distance in metres, within the confines of which the temperature becomes greater by one degree is called the geothermal step, while the rising of temperature every one hundred metres is referred to as the geothermal gradient. These values are subject to alteration from one place to another. On average the geothermal gradient comprises between one and three degrees for one hundred metres, reaching tens of degrees in places. As

has been considered, it is lower in the ancient folded geological regions and higher within the areas of modern volcanism.

I happened to go down into the deep mines in Mexico. At the depths of over 600 metres the temperature in the drain pipes reached 53 degrees! Try to imagine how hard it is for the miners to work in these conditions. They work at the face for not more than four hours, and after a four-hour rest in the open air they go back there again. In this hot subterranean 'bath-house' the clothes one wears are very scarce indeed. It is obvious that in the region of late Tertiary and Quaternary volcanic activity a reserve of heat in the near-deposited magmatic chambers has still been preserved. The rise in temperature with the increase of depth in the Prshibram mine in Czechoslovakia is equally as great.

There exists a still higher geothermal gradient in the proximity of the now acting volcanoes, where at the depth of 40-60 kilometres and less we find centres of hot melted mass—the magma. At the exit to the surface the temperature of the magma reaches 1300 degrees, while at the depth, as can be shown by the calculations, it is 1500°. The geothermal gradient has proved to be much higher than it was supposed to be in the district of the deepest Kola well, which intersects the ancient rocks. Instead of the expected 100° at the depth

of 10 thousand metres the temperature equals 180°.

The subterranean heat is an important source of energy for the future. Now too it is used at the thermal power station in Kamchatka. It is also used for the heating of dwellings and greenhouses. No special comment is required to prove that on account of high temperature we are not able to penetrate into the markedly deep parts of the Earth.

Chapter 3
The Deep-seated Structure of the Earth

As far as its composition is concerned the Earth is not homogeneous. The assumption is that its depths contain heavy dense masses. This is the conclusion which was drawn by the famous French scientist G.A. Daubrée as early as the last century. He pointed out that the Earth's density estimated by Newton in 1736 (in respect of volume and mass) is considerably greater than the density of those rocks with which we are familiar on its surface (the specific weight of granite is 2.8 g in one cubic centimetre). According to this scientist it followed that at the depth there had to be considerably heavier masses. In order that one could imagine the possible composition of the Earth's interiors, Dau-

brée turned to meteorites in the middle of the last century. What he thought was that meteorites were formed from the fragments of destroyed planets that looked like the Earth, and could therefore give us some idea about the composition of our own planet.

Among the meteorites, or cosmic bodies that fall upon the Earth, various of their types have long been established, e.g. there are the metallic or iron meteorites, containing nickel in addition to iron; iron and stony meteorites and those where stones are preponderant. In Daubrée's opinion it is precisely this kind of heterogeneous material that enters into the composition of the Earth. The heavy material consisting of iron and nickel was concentrated in the core of the planet and received the name of 'nife' (nickel-iron). The mantle of the core made up of heavy silicates of iron and magnesium, with their composition having much in common with the stony meteorites, was called 'sima' (silicon and magnesium). Rocks of this kind are actually found among the ultrabasic silicate rocks (poor in silicic acid), or peridotites that can be discovered in the deep fissures of the earth's crust. The outermost light mantle was called 'sial'. It is characterized by rocks of the type of granites that are rich in aluminium and silica.

Much time has passed since Daubrée discovered the zonal structure of the Earth and introduced the concepts of the metallic core and silicate mantles, but the basic precepts of the scheme suggested by him have not gone into abeyance. The old terms have also remained. Geologists do speak of simatic and sialic mantles of the Earth. These ideas were substantiated by the research carried out by the geophysicists.

Unfortunately, we cannot follow the example of the characters from the books of Jules Verne and penetrate into the centre of the globe and come into contact with our antipodes. The temperature there measures thousands of degrees! But what we still have at our disposal are the 'thinking' machines, which help us to investigate the deeper regions of the Earth.

The main method of studying the interiors of the Earth consists in the deep seismic probing and is based on the research into the propagation of seismic waves in the course of the artificial explosions or earthquakes. The rate at which they are propagated regularly grows from 5 kilometres per second in the outer mantle of the Earth to 11 kilometres in its centre, which finds its expression in the rise of the density of the Earth's masses as the depth increases. Against this background we also find 'sudden changes', or differences in the velocities, corresponding to the inner sur-

face sections of the spheres of not the same density.

According to the data of seismic investigations the contemporary model of the deep-seated structure of the Earth is the following. In its centre we have a hard metallic core which is wholly in congruity with the concepts pertaining to the 'nife' and whose composition is similar to iron meteorites. The inner core is surrounded by an outer core which is also of metallic composition, though of liquid variety (the transverse seismic waves are not propagated in it as is the case with solid medium). It is assumed that exactly within this liquid there exists the generator of the Earth's magnetic field.

The Soviet scientists S. Monin, O. Sorokhtin, and L. Zonenshein have recently come up with a suggestion that on the border of the outer core with the hard shell (mantle) enveloping it there occurs a convergence of heavy metallic elements towards the centre of the Earth, which leads to the growth of the planet's metallic core with the processes of melting and chemical division of melts in progress. These authors assume that near the border of the outer metallic core there exists a shell consisting of iron oxides.

The concept that the Earth's mantle consists of silicates of iron and magnesium may well be considered to be widely spread.

The mantle is compared to the stony meteorites or chondrites (meteorites consisting of rounded globules or chondrites), the composition of which includes ferromagnesian silicates, as well as with ultrabasic rocks poor in silica of the type of peridotites. They can be found in the deep-seated parts of the valleys on the continental slopes of the oceanic floor and within the massifs of ultrabasic rock formed from the deep-seated melts that rose along the fissures, or the same kind of hard rocks which were pushed out of the mantle along the deep fissures under the activity of tectonic forces. From the outside the mantle looks like a greyish-green rock of the serpentine type which is used in sculpture and architecture.

The mantle is saide to comprise the lower and the upper part. The border line between them is not that clear-cut. What draws our particular attention in the upper mantle is the layer at the depth of 100-120 kilometres from the surface of the Earth, where the velocity of seismic waves markedly decreases. It is assumed that this is where the weakened zone of partial melting, or the asthenosphere lies. The scientists consider that the asthenosphere is precisely what is responsible for the numerous processes that are generated in the depths of the Earth, viz. the intrusion of melts, tectonic movements of the earth's crust, and others.

Above the asthenosphere we have the lithosphere—the upper hard envelope, bringing together the upper part of the mantle and the earth's crust. The borderline between the crust and the Earth's mantle is settled according to a clear-cut division of surface, marked by a difference in the velocities of the seismic waves. This surface has been named after its discoverer—the Yugoslavian geophysicist A. Mohorovičić—the Mohorovičić discontinuity, Moho, or simply M as its variants. In the oceans it is situated at the depths of 5-10 kilometres, while on the continents the average equals 50 kilometres. It is suggested that what lies on top of it is the 'basaltic layer' (the rate at which the waves are propagated here is the same as in the basalts) and still higher there is the 'granitic layer', which has also received its name tentatively in comparison between the velocities of the propagation of waves and those typical of the granites. The outermost shell is formed by the sedimentary layer.

The main part of the Earth—1/2 of its radius and over 60% of the mass—is composed of the mantle. This is also in conformity with the greater propagation of stony meteorites from which, as is regarded, the mantle originated. The core is twice smaller in mass (the radius of the inner hard core is 1271 kilometres, while the cross section of the liquid outer core

equals 2200 kilometres). Extremely small is the thickness of the earth's crust. It is only 1/200 of the Earth's radius, which is but a thin film on its surface! And the sedimentary outer shell is even thinner!

It is only the latter that we know to a certain extent. It is composed of the sedimentary rocks which are known to us, e.g. sandstones, clayey schists, and limestones, that break through these masses with granites and other igneous rocks.

By nature of their activity the geologists are confirmed observers and empiricists; anything unknown to them becomes the object they want to see themselves and, if possible, even to touch. There is no other way but to bore! Then we shall check whether the geophysicists are right or not. It would be possible to bore the earth's crust so as to intersect the Moho's discontinuity. Some 5-10 kilometres present no problem. If only we could reach the mysterious mantle! Is it really such as we imagine it to be?

But first it was decided to go down as deep as the actual basaltic layer. It was regarded that it lay close to the surface or even came out to it in the region of the Kola Peninsula. And it was there that the first superdeep well was located.

The results of boring operations proved to be quite unexpected. There where according to geophysical data the basalts (the basaltic layer) were supposed to be, the

well intersected light archean gneisses. It goes further along them to the depth of already more than 12 kilometres. The basaltic layer has disappeared! All this looks like a geological thriller. The basalts, or the fundamental layer, according to which conclusions were drawn about the deep-seated structure of the Earth and the thickness of its upper shells, vanished into thin air!

The Kola well is remarkable indeed! What produces a great impression is its huge structure on top of the well and the dexterously manipulating mechanisms that are used when lifting and lowering the pipes, where the manual work is reduced to minimum. It is hardly creditable, but the well went down to the depth of 12 thousand metres. And yet the core samples reveal exactly the same rocks—the light gneissose granites!

Should we be exalted or frustrated? Suffice it to say that the well did not undergo the expected basaltic layer! I think it has been a great success!

The data furnished by the boring operations make us more cautious as regards the geological interpretation of the results of geophysical research, taking into account the fact that the increased velocities of the propagation of seismic waves in the deeper regions can be brought about by various causes. And it is not only the growth of the

density of rocks, the impact of which was not disregarded before either, but also the characteristic features of the tectonic structure and the geological history of the territory under analysis. In the region of the Kola well-drilling density of rocks was also influenced by tectonic dislocations—the large flat joint of the overthrust zone. While masses of rock moved along it the rocks became markedly more compact. In other words, the factors underlying the changes in the velocities of the propagation of seismic waves can be of different kind, and one should be very careful in interpreting any information about them.

The deep-seated structure of the Earth could be more fully apprehended where we combine the geological observation with the boring of superdeep wells and a comprehensive geophysical research. The number of deep wells will still remain high. Some of them will go as far as the Moho discontinuity and will help us to establish what is determined by the change in the composition of rocks or the difference in the degree of their compactness. In its turn, this will make it possible to draw the necessary conclusion concerning the structure and the origin of the Earth on a much wider scale.

Chapter 4
The Development of Views on the Origin of Earth and Other Planets of the Solar System

The questions pertaining to the origin of planets have occupied the minds of scientists for a long time. In the main two trends of such views have been established. Some researchers assumed the originally 'cold' beginning of planets, while others adhered to that the inception of planet was 'hot', and that they were formed as a result of the breaking away of fiery 'pieces' of solar matter or the heating of cold particles in the vicinity of the Sun.

The idea that planets originated from a coagulated cold substance was advanced as early as the sixteenth century by the French mathematician and philosopher René Descartes, who explained the emergence of heavenly bodies by the whirlpool movement of matter. Later Georges Louis Buffon, the French natural scientist and a foreign member of St. Petersburg Academy of Sciences, suggested the 'hot' variant of the origin of planets of the solar system, which, according to his theory, were formed when parts of the Sun were torn away by the passing comet.

In the eighteenth century two other hypotheses were being developed at the same time. One of them was put forward

by Pierre Simon de Laplace, the French mathematician and astronomer, also a foreign member of St. Petersburg Academy of Sciences, and quite independently of him by the German philosopher Immanuel Kant, an honorary foreign member of St. Petersburg Academy of Sciences, who came up with his own hypothesis. The history of science brought together the names of these two scientists. Their theory pertaining to the origin of the Earth from the rarefied matter (a return to Descartes) came to be called the Kant-Laplace theory, though their outlooks were not absolutely unanimous in their opinions on some of the details.

Laplace regarded that the planets originated from the rarefied matter from the hot nebula, in the centre of which there appeared our own Sun. Both cooling and condensation resulted in an increase in the vicinity of rotation and the separation from the nebula of a series of rotating rings upon which the planets were formed at a later period.

The cosmogenic hypothesis introduced by Kant derives from the assumption implying the existence of initially cold substance that was continually being coagulated from the rarefied interstellar materials. According to both Kant and Laplace the Earth as well as the other planets had experienced the stage of heating in the course of condensation and subsequent cooling.

Practically at the same time similar ideas were expounded by I. Ertov, the self-taught philosopher, who submitted a special report to the Academy of Sciences.

The theory concerning the formation of the Earth that received the name of planetesimal hypothesis was explained in 1901 by Forest R. Moulton and Thomas C. Chamberlin. In their opinion the planets emerged in the spiral nebula from the innumerable hard small cosmic bodies (planetesimals), which, rotating round the central core—the Sun, confronted and accumulated into clots. In the rarefied nebula and under the heat of the Solar rays there took place the melting of the substance and the appearance of first the easily fusible metallic globules that were attracted to each other and were then concentrated in the iron and nickel cores of the planet. Later there occurred the crystallization of iron silicate globules (chondrules), which formed the Earth mantle that envelopes the core.

In 1916 Sir James Jeans returned to the 'hot' hypothesis of the formation of the Earth, which restored G. Buffon's idea that the Earth was torn away from the Sun. According to Jeans there had passed near the Sun a star twice bigger in size, which resulted in that a tidal wave broke off a huge solar protuberance—the bulge upon its surface, which was precisely

separated into parts, thus giving rise to planets. At first they were melted spheres with liquid content. The inner planets were small and dense; the outer ones represented enormous gaseous balloons of low density (Jupiter, Saturn, and others). Jeans's hypothesis was refuted. However, the arguments between the proponents of the 'cold' and the 'hot' origin of the Earth did not stop there.

In a considerably later period the ideas concerning the cold formation of the Earth were farther developed and mathematically consolidated by Academician O. Schmidt and others. According to this theory the division of matter took place as early as the time of the rotating cloud, when the heaviest particles of metals occurred in the centre of this cloud and the lighter ones were situated along the periphery, which resulted in the formation of the mantle and the earth's crust.

At the same time with Schmidt and at a somewhat later date the said 'cold' concept was being elaborated by the Dutch scientist H. Berlage. Those who actively adhere to these ideas at present include the prominent Dutch scholar M. Van Bemmelen.

The fact that matter could have been differentiated in space was pointed out by A. Fersman. This version is now being revived by petrologists who study the origin of the Earth in terms of physicochemi-

cal processes. The most active proponent of this trend is the well-known American geophysicist M. Ringwood.

Hence, the concept implying the distribution of matter along the zones of the Earth finds its explanation either in that it was divided as early as when it was in the dust cloud as a result of gravity, or in the course of the subsequent fallout of particles of different weight. Both these variants provide a rational explanation of the causes that underlie the changes in the density of the Earth's substance in connection with the depth.

What presents special interest in the light of the hypothesis concerning the subsequent fallout of lighter particles upon the Earth's surface is the ideas put forward by the Dutch scientist J. Dana, who in 1965 came up with the assumption that round the Earth there had originally been three rings, consisting of dust material and asteroids. The nearest ring, when attracted to the Earth, gave rise to a layer of loose material the thickness of which was 65 kilometres. At the expense of the two outer rings there emerged the Moon. Nowadays these ideas are supported by the Dutch scientist M. Van Bemmelen, who speaks, however, of three dust rings, similar to those of Saturn, of which the nearest one was drawn to the Earth and scattered along its surface.

The concept pertaining to a later fallout of matter, from which the earth's crust was formed, is also developed in the hypothesis concerning the so-called carbonaceous chondrites, enriched with water and carbon. This hypothesis finds its support, in particular, with the Soviet scientist V. Barsukov, corresponding member of the USSR Academy of Sciences. He assumes that it was precisely these meteorites enriched with water, which are even now found among the celestial bodies falling on the Earth, that became the basis of the upper part of the earth's crust and produced the material for the future origin of life. However, this interesting supposition is in contradiction with the latest data referring to the finds of the so-called organized matter in carbonaceous chondrites.

M. Ruten assumes that carbonaceous chondrites which are relatively rare among the meteorites are actually fragments of some other planet, while their organic compounds may be the witnesses of extraterrestrial life. Thus, you can see for yourselves how many contradictory opinions and ideas there exist on such a highly significant question as the cause that determines the zonal structure of the Earth.

But this does not put a stop to all those controversies. Quite a few researchers acknowledge that after its formation and as a result of compression as well as the

disintegration of short-lived radioactive elements the Earth became heated. This compression was exactly what promoted mass volcanism in its upper mantle.

Those concerned with this problem have different ideas about the scope of the heating process. Kant and Laplace thought that the Earth represented a melted globe, while mountains emerged in the course of its cooling as wrinkles on a desiccated apple. A. Vinogradov speaks of a partial melting of matter in some zones, which led to the uplift of volatile and light elements towards the outer shell and encouraged the creation of its light granitic core.

Within the past few years concepts that have much in common with the ideas of Kant and Laplace about the overall melting of the Earth have been expressed. They are supported by such petrologists as M. Ringwood as well as corresponding member of the USSR Academy of Sciences A. Marakushev. According to Ringwood the concept of the general melted state of the Earth makes it easier to explain the division of its matter with the suspension of the heavy components closer to the core. In his opinion this is a more real means than the division of matter according to the degree of its weight in the gaseous dust cloud.

It should be mentioned that by accepting the hypothesis concerning wide-range melt-

ing of the Earth in its deeper regions, it would also be possible to understand the origin of the system of planetary faults that give rise to a regular network. These systems of fissures are supposed to be on Mars. From the outside this network of planetary faults reminds us of the contraction fissures, which emerged during the cooling stage of lavas.

How long did this period of the formation of the primary Earth and its differentiation according to the specific weight last? It is assumed to have covered 0.5-1 billion years, though according to the views of other scientists the span must have been equal to a quarter of a billion years.

In establishing the duration of this period we can already receive no little help from the radiogeological data. Thus, at present we know of the rocks whose age is approximately 4 billion years with apparently sedimentary ones among them. This means that 4 billion years ago there existed the hydrosphere and sedimentation was in progress. The formation of hydrosphere in the early stage of development leads itself more readily to be understood if we follow Dana's idea and M. Van Bemmelen about the fallout of particles of the uppermost layer at a considerably later time than the development of the planet itself.

According to Van Bemmelen, at that time there had already been every possibil-

ity for the formation of atmosphere from the water vapours, to be followed by hydrosphere at the expense of ice crystals. According to Van Bemmelen, in those days the ocean covered the Earth and its surface was in part covered with the protrusions of individual volcanoes, from which there poured out the lava that was originated in the deeper and heated shells of the Earth. The further evolution took place in conjunction with the volcanic phenomena and the formation of sediments at the expense of the destruction of volcanic cones and the redeposition of the material on the ocean floor.

There is yet another hypothesis pertaining to the origin of the Earth: it is said to have been originated from a cluster of solar material and the condensation of basically gaseous (plasma) substance. To prove this assumption the 'gaseous breathing' of the Earth is usually adduced. The said 'breathing' is associated with the emission of helium and hydrogen from the depths of the Earth.

However, there are still many scientists who do adhere to the former concepts of Kant and Laplace that the Earth emerged from the hard particles.

Two models of such development are regarded: the homogeneous one, implying a cloud that was once only formed from the hard particles and the consequent differ-

entiation during the compression stage with the formation of shells of different density (Academician O. Schmidt's hypothesis), and the heterogeneous model, which takes into account the possibility of the subsequent fallout of first the metallic and then the silicate components of the Earth (Academician A. Vinogradov's model), and in conclusion—the fallout of the lightest carbonaceous chondrites, which served as the material for the upper sialic shell and which had brought down to Earth the organic compounds—the brick that lays the foundation of the life in the future (the model introduced by V. Barsukov et al.). The variant of heterogeneous model serves as the expression of the hypothesis introduced by the Dutch scientists Dana and Berlage and supported by M. Van Bemmelen, which concerns the fall upon the Earth of the former satellite (it is assumed that at first there were three of them!) that formed a complete cover of friable material (of the type of lunar regolith) in the upper mantle.

The Canadian 'precambrists' suggest their own variant of the formation of sialic continental core. According to M. Goodwin it originated at the place of an intense fallout of meteorites during the meteoritic bombardment in the first stage of the development of the Earth. A stream of meteorites covered not all the territory

but only a restricted area, loosened the earlier formed protocore, and crushed its material, after which there followed further transformations, which led to the creation of the sialic core under the activity of gases and solutions, that issued from the deeper regions. This was precisely how the primary continent Pangaea emerged. It was surrounded by the ocean where the processes of the formation of sialic continental core did not take place.

We can easily see how many interesting ideas are brought about by the problem of the initial stages in the development of our planet. It is considered that this problem can partially be solved when other celestial bodies are studied. However, this method can hardly be found to be universal for the interpretation of all the characteristic features pertinent to the development of the Earth. In many respects our planet is unique as far as its position in respect of the Sun is concerned. The same could be said of its relationship to the early development of the atmosphere and hydrosphere, which had determined the subsequent evolution of the uppermost shell of the Earth—the earth's crust.

Part II
The History of the Development of the Earth

Chapter 5
The Dawn

Something has already been said about the origin of the Earth according to the now existing concepts. But how could our planet have been formed out of a shapeless gaseous dust cloud with gigantic asteroids and infinitesimal dust?

A large number of cosmic, planetary, already geological and biological events proper had finally led to the creation of our Earth—the unique planet with its atmosphere, hydrosphere and life. Features of the original material from which the proto-earth was formed have been destroyed with ages. Perhaps we could find them on the Moon, on some other planets or asteroids.

The Earth began to develop as a hard body in the so-called 'lunar stage'. It was a cold planet furrowed by the sinks of falling meteorites. What was typical of that period was the Earth's own processes and its own regularities that did not recur in the future: the bombardments of meteorites caused the fracturing of our planet's hard material and the melting of the matter at the temperatures of up to 1000 degrees. What also influenced the Earth's surface was

the so-called solar wind, the bombardment with the nuclear particles and space radiation. The material was transported along the earth's surface and there emerged the first loose layer of the Earth, which was very much the same as the one that was found on the Moon though it must have been much thicker.

The traces of the subsequent stage, or that of the initial volcanism, can be discovered in the ancient volcanic rocks, which would serve as evidence how the Earth developed after the beginning of the heating process, mass outflows of lavas, the formation of atmosphere, at first of the carbon dioxide type with water vapours (?), and then with oxygen, the hydrosphere with the formation of sedimentary rocks, and lastly, the origin and development of life. It is quite natural that the deeper we try to penetrate into the past history of the Earth, the fewer authentic facts we discover and the more space there is for hypotheses.

The history of the development of the Earth and its stages is reconstructed by the geologists who study the subsequence of the deposits of the earth's layers and geological phenomena which led to their formation.

The fundamental and long established rule in geology says that the deeper (lower) the layer lies, the more ancient it is. However, there are exceptions to it, as is, for instance, in the case of 'reversed' bedding

of layers though basically the rule is quite applicable

For the reconstructions of the early stages in the development of the Earth the geologists turn to the ancient rocks—the silent witness of those violent geological processes that took part in the remotest part of the Earth's history. What are then the objective data that help to determine the age of rocks and distinguish the most ancient masses from the younger ones?

For comparatively recent formations whose age is within the limits of 570 million years and less (which is not so much in terms of the Earth's time) the paleontological method is used. It consists in establishing the relative age of rocks of the fossils buried in the layers—the remains of extinct organisms, which regularly replaced each other in the process of the evolution of life on Earth. But this can be employed only for the very latest stage—the Phanerozoic period (when traces of life are evident), which began with the Cambrian period. All the earlier periods in the history of the Earth comprise an enormous interval of time lasting 4 billion years, which is collectively called the Precambrian period. Nowadays the Precambrian period is divided into large subsections. This was achieved with the help of the radiological method of establishing the age of rocks and minerals. This method, as one of the results of the

great discovery of radioactivity made by Pierre and Marie Curies, enabled the geologists to have a powerful tool for the study of the past of our planet. Since the velocity of radioactive disintegration for each element is known, the radiological age of rock can be established by the relationship of the qualities of the initial and newly-formed elements.

The most convenient elements are those whose velocity of disintegration is 'commensurate' with the scope of the Earth's time. To determine the age the geologists use such radioactive elements as uranium and thorium, which in due time become transformed into lead, or they clarify the relationship of different isotopes of lead, which is known as the so-called lead method. The potassium-argon method is also widely employed. It consists in determining the relationship of the amount of potassium contained in a rock and the argon newly-formed from it. The rubidium-strontium method is yet another one as is based on the transformation of the atoms of strontium into those of rubidium. These elements, which are characterized by the prolonged time of disintegration help us to establish the age in terms of millions and billions of years. However, for a brief period, measuring only thousands of years, the radiocarbon method is used. At present the geologists have the chronometer, which allows

them to determine the age of rocks and the time when various geological events took place.

The most ancient age is 4.6 billion years. It is established for one of the meteorites, and it is precisely what is taken to be the age of the Earth and other planets. Terrestrial rocks are characterized by lower figures, such as 3.5-3.7 billion years, with some of them measuring up to 4 billion years.

What are then the most ancient rocks?

The oldest volcanic rocks of the primary core were rich in iron and magnesium, though poor in silica. However, in due time there took place a transformation of the earth's crust. On the surface under the influence of the hot atmosphere consisting of the vapours of sulphuric acid, fluoric and chlorous compounds, there occurred the disintegration of hard rocks of the initial basaltic 'shell' which was enveloping the Earth. The basalts were being disintegrated, and with the emergence of the primary water streams under the cooling of the atmosphere the dissolution of ferriferrous and magnesial compounds and their discharge into the depressions filled with water took place. What remained in their place included the insoluble compounds of silica (SiO_2) in the form of powder- and jelly-like masses, as well as the relatively immobile alumina—aluminium oxide (Al_2O_3). Thus, already in the water basins there was the

division of substance into more acid and lighter variety (silica, alumina) and the basic and ferromagnesian components; masses of siliceous deposits were formed, which, some time later—in the process of recrystallization—were transformed into quartzites, the rocks consisting of quartz.

In the deeper regions there also occurred the division of matter in the course of the deposition of crystallized heavier minerals—iron and magnesium—and the enrichment of the remains of melts with the lighter ones, or those rich in silica. As early as the initial stages in the development of the earth's crust the outflows included not only the heavy basaltic, or basic lavas, but also those that were more acid. The light components of these deep-seated melts rose in the direction of the surface as parts of the solutions too. These hot solutions, enriched with silica and alkali, also disintegrated the primary basalts, and in the place of ferromagnesian silicates alkaline feldspars and quartz were formed. This was how granites forming the domes, or the initial cores of the future granitic shell of the Earth, were formed. Granitic domes began to develop already in the earliest stage of the development of our planet —about 3 or 3.5 billion years ago.

Meanwhile at the depth too there took place the melting of the primary core, the separation of the acid light granitic melts,

and their uplift along the fissures into the upper levels of the earth's crust. This mass manifestation of granitization, which was particularly typical of the period of about 2.5 billion years ago, is connected with the concentration of various mineral resources, e.g. such rare metals as tantalum, niobium, beryllium, and tin. It was a unique and gigantic period of the 'release' of huge masses of ore material, that entered together with the melts from the mantle, which at that time underwent the most intense evolution.

The gneissose granitic domes were surrounded with greenstone belts, or troughs, composed of altered basalt. These two types of formations were exactly what comprised the initial shell of the Earth. These deep-seated rocks of the primary stages are exposed in the most ancient structures. In the Soviet Union they are found in the Aldan and the Stanovoy ridge. They are widely developed in Africa, Western Australia, and South America—the continents that are excessively rich in various minerals.

It follows from what has just been said that the earth's crust had for a long time been developing under the influence of deep and surface processes. According to the calculations made by E. Markhinin the number of eruptions of huge masses of volcanic products would have been ample to cover the whole volume of the sialic con-

tinental shell known to us. The destruction of primary rocks led to the accumulation of thick masses of sediments of fragmental, chemical, and organic origin.

We cannot determine with any degree of precision the role of various processes in the formation of the earth's crust. We have even less information about the processes of its possible disintegration in the course of its subsistence to greater depths. It is precisely this problem that is the main one in the solution of the question pertaining to the origin of oceans, their priority or secondary character. Did the oceans of the Pacific type exist beginning with the early stages in the development or did they emerge in the place of the former continents that were destroyed in the later period? If the oceans did not exist before where then did the huge volume of water, which is now held, for instance, by the gigantic Pacific Ocean bowl, find the required place for itself?

Undoubtedly in due time the quantity of water increased at the expense of the volcanic eruptions, though presumably not to such an extent that could compensate for the whole of this enormous volume. As far as the continental seas are concerned, or those that periodically flooded the continents, particularly the northern ones, their depth was not so considerable as to include the said volume of water. Hence, it follows that probably as early as the initial stages

the topographic irregularities that emerged during the formation of the Earth were precisely the depressions that held those masses of water.

The late Proterozoic (Riphean?) period was marked by the formation of deep planetary faults as a result of overall fracturing of the Earth. There appeared long troughs or geosynclines the development of which covered no little span of time. In addition to this there took place the division of the earth's crust into the principal tectonic elements: the stable ancient crystalline massifs—platforms and the mobile zones dividing them, the troughs, or geosynclines, in which volcanites and marine sediments accumulated, and after the crumpling of layers into folds and the uplift mountain structures had developed.

There exists a universally reorganized periodization of the development of the Earth. The most prominent subdivisions in the history of the Earth are eons: Catarchean (4.5-4.6-3.5 billion years), Archean (3.5-2.6 billion years), Proterozoic—at present it is further classified into Carelian (the Lower and Mid Proterozoic—2.6-1.7 billion years), and Riphean (the Upper Proterozoic—1.7-0.57 billion years), and lastly the Phanerozoic eon (0.57 billion years and the contemporary period).

The duration of each eon is close to one billion years; it is less in the short Phane-

rozoic eon, that has not yet been completed, and in which greater subdivisions are singled out, viz. eras, comprising periods or systems, as well as geological series and stages.

The boundaries and borders of eons, eras and systems not infrequently coincide in time with the manifestations of intense deformations of the earth's crust, covering vast regions or the whole Earth itself. There were many of them. Those that will be discussed further are the most important ones. What we have is the periodicity of the stages in the development—the rhythms with the interval of approximately 200 million years. This rhythmicity is reflected in the alternation of transgressions (advances) and regressions (recessions) of the sea, connected with the smooth vibrations of the earth's crust, in the periodic manifestation of intensive folding, the change of climatic conditions and the character of sediments. The cause underlying these changes may be connected with the processes in space, possibly with the influence of the clouds of star dust, through which the Sun periodically passes in its movement in the general stellar system of the Galaxy. The periods pertinent to the manifestation of folding with the subsequent change in the position of land and seas, and variations of the climate are also marked by the replacement of living organisms which also determines the bor-

ders of the later Phanerozoic geological systems. What was it then that had its effect on the emergence of life everywhere in the ancient seas of the Earth? The cooling of seas? The peculiarities of their saline composition or the burst of the supernova?

The Earth had for a long time experienced the intense tectonic movements. The advance of waters upon the platforms (transgressions) often coincided with the uplift of their neighbouring geosynclinal troughs, and there took place a kind of 'transfusion' of waters into the contiguous valleys.

Such was the ancient history of the Earth. In due time the forms of structural elements changed: from gently sloping domes and annular troughs enveloping them to long and relatively straight geosynclines, which determined the direction of folded chains that appeared later.

Intense tectonic movements not infrequently manifested themselves in the Precambrian period. A. Monin distinguished 19 tectonic and magmatic epochs, of which 15 found their expression in the Precambrian period. Three epochs of the Precambrian period which have not received any names were singled out by O. Sorokhtin. Some of the tectonic and magmatic activities were global and were observed throughout the whole Earth; others manifested themselves only within some of its parts. At the time separating the Precambrian and Phanerozo-

ic periods (with apparent life typical of the latter) the multiphase Baikal folding found its expression.

The early geosynclinal systems include the Baikal troughs that fringe the primary ancient platforms, and then the Mongol-Okhotsk and, presumably, the Mediterranean zones that had emerged along the fractures in the Proterozoic period. Along the Mediterranean zone there were seas of the system called Tethys, which intermittently continues to develop until now. The tectonic latitudinal zone of Tethys which extended from the West of Europe to Eastern Asia (the Himalayas), separated the main northern continent Lavrasia from the southern one known as Gondwana. The meridional branch of this belt lay to the north across the system of fractures of the Ural geosyncline, which had already in the Proterozoic period divided the Russian and Siberian platforms. Curving itself into an arch, the meridional structure of the Urals continues in the mountain-folded systems of the Southern Tien Shan. The latitudinal fractures divided Lavrasia in the East, thus separating the Siberian and Chinese platforms from each other.

The folded belts that emerged along these mobile zones which had been developing for a long time can be found even now in the mountain-folded structures of the main structural zones of the Earth.

In the Phanerozoic period there emerged a younger Pacific mountain-folded belt, and Gondwana was separated into parts. However, the first and the most important structural elements of our planet originated in the Precambrian (Proterozoic) period, at the time of the principal overall segmentation of the hard earth's crust.

Chapter 6
Life. The Earth's Chronicle

How and when did life emerge on our Earth?

The question of the origin of life as well as that of the planet as a whole is debatable. There can be no doubt that the life on Earth began very long ago. It has been discovered that layers of ancient rocks are enriched with organic compounds.

The unicellular bacteria which represent the initial stage in the development of life could not leave after themselves a large number of historical traces. Hence, the most ancient layers are preponderantly the mute pages in the annals of the Earth. The use of new methods of research, in particular the electronic microscope, will probably help to penetrate more profoundly into the secrecy of the development of the most ancient forms of life. Information has recently been received concerning the discovery of some of the imprints of unicellular organisms in

the ancient masses that are 3.6 billion years old.

Witnesses of the past intense life in the oceans are the so-called stromatolithes—the ramifying column-like structures—which functioned as the envelope for the blue-green algae that were developing then. It was precisely they that inhabited the ancient seas of our planet in the period as far back as at least 2.5 billion years ago. The forms of stromatolithic structures changed in the course of time, which helps to use their fossils in identifying the age of the ancient marine deposits.

It took the matter, varying from age to age,
Some billions of years to correctly presage,
How a bacterium one day,
Will to a human being pave its way.

In spiral movement so distinct
Some genera became extinct,
While others soared so very high
Under the blue auspicious sky.

The animals that lived in the ancient seas have practically left no traces of their life. The Earth's history most definitely begins with the Cambrian period (570 million years). In the Cambrian layers we find many fossilized animals. More than 1500 species! The main ones are the trilobites—the arthropods that had very much in common with the crustaceans we see today. They had a hard armour which protected them from their enemies. These armoured 'knights' did not emerge all of a sudden

either. It was quite recently that imprints of their ancestors—the armourless, or 'naked', trilobites—had been discovered.

The remains of trilobites have reached us in the form of well-preserved fossils. Their oval armours which resemble the lockets can now be found in a large number of deposits. But at that time their discovery was a real sensation. Trilobites were first found in 1835 in the sediments of the Cambrian mountains in Wales by the British scientist A. Sedgwick, who called those layers Cambrian and the animals trilobites. This term exactly reflects the trimembral structure of their armours, which consist of the axial part and two lateral segments. Their armours are divided into three parts across too. It is the head, the body, and the tail. Besides, trilobites have a large number of cross-sectional disconnected bands (segments) or soles.

Trilobites used to crawl on the sea floor and could roll themselves into a ball owing to the absence of a hard articulation between the segments. They watched the marine world, the swaying ribbons of algae with their round bulging eyes. Some of them had a pair of eyes, others had many, and still others (apparently the abyssal varieties) had no eyes at all and were totally blind. We have dwelt on trilobites in such detail because they are the first remains of animals that have reached us, and are the most impor-

tant fossil organisms which help us 'to read' the initial pages of the Earth's chronicle: they also had neighbours—the other animals which had left their traces in the fossils.

In the history of the Earth the time beginning with the Cambrian period received the name of Phanerozoic (when life was apparent), while the enormous interval preceding it and lasting 4 billion years was called Precambrian.

The Precambrian period has already been mentioned here. It is time we discussed the Phanerozoic period, which is divided into time intervals with great precision.

The following eras are distinguished in the Phanerozoic period: Paleozoic (ancient life), Mesozoic (middle life), and Cenozoic (new life). Eras are further subdivided into systems: in Paleozoic they are Cambrian, Ordovician, Silurian, Devonian, Carboniferous and Permian; in Mesozoic the systems include Triassic, Jurassic, and Cretaceous; the Cenozoic era—Paleogene, Neogene and the Quarternary period. In what follows we have a brief account of each of these periods.

The Cambrian period (570 $\pm$ 30-500 $\pm$ 15 million years) was the turning point in the development of life on Earth: there appeared skeletal, armoured, and shell organisms, and precisely their remains that have preserved so well until now that help

us to determine the relative age of the layers of sedimentary rocks.

The Cambrian period was remarkable for the spreading of seas. They fringed the ancient massifs of land. Wide and long geosynclines that had emerged as far back as the Proterozoic period continued to develop—the Mediterranean geosyncline and its arms, the Meridional Ural geosyncline, which separated the Russian platform from the Siberian one, and the latitudinal Mongol-Okhotsk geosyncline which divided the Siberian and Chinese platforms. The sea also flooded the platforms: the Siberian platform and the greater part of the Chinese and Russian platforms.

The Cambrian geosynclines were characterized by the deposition of such volcanic and fragmental rocks as sandstones and clayey schists; at the expense of animal shells there emerged thick masses of limestones. The communication between the seas that flooded the vast areas was what accounted for the wide-range settling of animals and on the whole a monotonous composition of the plethoric sea fauna.

The blue Cambrian clays of the platform 'mantle' in the vicinity of Leningrad are specific indeed. We saw them during our geological expedition to Popovka station. And it was near the station where we saw quite a few interesting things. There were wonderful sections of deposits: the Cam-

brian, Ordovician, and Silurian varieties. We heard about them from P. Gryushe—the first who took us into the 'temple of geological science'....

It all surprised us greatly. The clays were soft and plastic—quite fit to be used as modeling clay. As Pavel Gryushe explained to us, they laid unperturbed for half a billion years because they were on top of the hard Baltic shield. As far back as the remote Precambrian period the rocks of this shield underwent numerous deformations: they were melted through by huge massifs of granites and did not lend themselves to any folding processes now. The blue clays that surmounted them remained almost the same as they were in the Cambrian period.

But at the time when the stable ancient blocks of platform 'dozed in their enchanted slumber' in the Cambrian geosynclines—the troughs along the deep faults—there had already begun marked perturbations. That was where Pluto could really manifest his powers.

Along the faults there rose and flowed lava and thick masses of volcanic and sedimentary rocks were deposited. Later these layers were heavily crumpled into sharp folds (in contradistinction to the rocks of the platform mantle that have preserved a horizontal position). Deep melts had on a numerous occasion penetrated into these zones, which gave rise to the crystallization

of igneous rocks, accompanied by various ore deposits.

The magmatic activity had manifested itself most prominently during the last phases of the Baikal folding. The Baikal folded zones are extended into the Baikal region (hence its appellation), into the Stanovoy ridge, in Tuva, in Western Siberia. They comprised large deposits of iron, copper, and other ores. The sediments of the Cambrian age, however, contain deposits of salts and pyroschists.

The Ordovician period which followed the Cambrian period (500-410 million years) was named after the Ordovices who lived in the ancient Wales. At that time the very same sea basins were preserved as those that existed in the Cambrian period. The same could be said of the sea fauna though it became considerably more varied. Trilobites continued to inhabit the seas in which there were now new animals too. Particularly characteristic of the Ordovician period were the cephalopods known as orthoceratites. We came to know them through Pavel Alexandrovich in the geological section of the platform mantle in the proximity of that very same Popovka station. Above the blue Cambrian clays, of which mention has already been made, there lay light-grey limestones, within which we could see the cylindrical or conic bodies, or the petrified orthoceratites.

Later we could watch them many times in the form of inclusions in the plates of the Leningrad pavements well trodden by the pedestrians. Alas, nowadays the stone plates have been replaced by asphalt, and the students of the Mining Institute are deprived of the opportunity to study paleontology under their feet!

After some time, when we were already having our practice in Fergana, Pavel Alexandrovich acquainted us with the other animals of the Ordovician period—the graptolites. We used our hammers to knock out their fragile forms in the clayey schists on the slopes of the Isfairam river valley. We could not but marvel at the whimsical form of graptolites, their delicate 'branches' upon the layers of clayey rocks that resembled true ferns. However, they were colonial animals rather than plants. What Pavel Alexandrovich explained to us was that the forms of graptolites rapidly changed over the short period of their existence on the Earth (the period covering only some one hundred million years, which is only a moment in terms of geology!). This is exactly what makes it possible to accurately divide according to age the Ordovician and Silurian layers and even their individual stages (levels).

The Silurian period (430-310 million years) received its name from the Silurians whose

domicile was that part of Wales where those layers were first described.

The Silurian period was remarkable for a considerable complication of the animal world. If in the Cambrian period 1500 species were known to exist, their number in the Silurian period was already 15 000!

The distribution of land and sea was practically the same as what it was in the Ordovician and Cambrian periods. The geosynclines that fringed the uplifted platforms and communicated with each other extended as far as before. Sometimes the platforms (in the course of their suspension) allowed sea waters to enter them, out of which shallow-water sediments of platform mantles were deposited, whereas in the geosynclines that had remained since as far back as the Cambrian or Proterozoic period, there continued to progress such tempestuous events as the eruptions of volcanoes, which were ejecting metals from the very depths.

A highly significant characteristic feature of the Silurian period was the exit of animals from the seas to the land. The first to venture upon this move were the myriapods and the scorpions. In the fresh-water basins there appeared placoderms, and later (in the Devonian period) they settled in the seas.

The Silurian period yielded a large number of mineral resources. I can still remem-

ber our itineraries in the Urals where we observed the deposits of bedded copper ores in the volcanic masses. The sedimentary Silurian rocks contain deposits of phosphorites and pyroschists.

The end of the Silurian period was marked by the transition of plants from water to land (400 million years). This move was made by the rhypophytes—the most primitive vascular cryptogams, those with leaves and the leafless variety, which reproduced very much in the same way as the present-day ferns. Their age, however, was very short.

The Caledonian phase of tectonic movements gave rise to the systems of folded structures of the Northern Tien Shan, Northern Europe, and the Northern Baikal region. The mountain folded chains that had thus emerged joined themselves to the platforms, and surrounding them, gave them further 'growth'. There also took place an overall uplift of a large number of platforms, with the areas of platform seas undergoing considerable reduction. Conditions of life in seas and on land continued to change, which resulted in the advent of new forms of organisms. Hence, the Devonian system, which came after the Silurian period, became that particular landmark at which life had already more actively been conquering the then expanding land.

The Devonian system (405-350 million

years) was also found in Great Britain and got its name from the county of Devonshire (the British were most fortunate in discovering geological systems, weren't they!).

At that time the development of geosynclines was still in progress: the vast Mediterranean geosyncline, also covering Central Europe, its ramifications—the Ural, Mongol-Okhotsk, as well as the enormous Arctic geosyncline. Among the cephalopods the cylindrical orthoceratites were replaced by the spirally rounded ammonites; among the echinoderms sea lilies, looking like little flowers swaying on their long segmented columnar legs, were also widely developed.

Plants had changed too. The time of rhypophytes was brief (20-30 million years), though a highly important stage. At the end of the Devonian period they disappeared altogether. What became propagated on a wide scale in the Devonian period included the land algae-like plants, which are found near the water bodies and swamps. The same concerns herbaceous lycopods which in some cases reached great dimensions with the stalk as thin as one metre. In the forests there appeared the ancestors of future ferns, equiseta, and other plants, which at a later date burgeoned most lavishly in the forests of the later Carboniferous period.

The Arachnoids began to inhabit the land, and the miriapods continued to develop.

But the most important change concerned some species of fish! They now became wanderers on land! They were the dipnoans (lung-fishes) with which at the expense of swimming bladders there appeared something like lungs, and they could even breathe the air.

We know that the present-day dipnoans are able to withstand the temporary dehydrations of water bodies. They bury themselves into the silt and hibernate. This feature must have been inherited by them from their remote ancestors.

There is some reason to believe, however, that when their hibernation was disturbed by something, the fishes were compelled to live on land. The swimming bladders gave rise to lungs. The elements of their limbs—the hard excrescences at the place of ventral and pectoral fins—were quite ready now for peregrinations on land. By using them, the fishes could crawl on the bottom as far back as when they were in the water bodies. But now they were able to crawl and jump on land from one desiccating puddle to another. Some time later the fins acquired the form of legs, which was a highly significant stage in the emergence of land animals. The amphibians (in the Devonian period—the stegocephalians), with saurians, the ancestors of all the vertebrae yet to come, in their wake.

The Devonian period was characterized

by an enhancement of tectonic movements, which were the initial phases of the new Hercynian folding. The magmatic rocks of this phase are connected with the deposits of a large number of metals: chromium, iron, lead, zinc, copper, and gold.

As a result of the processes pertinent to folding and the elevation of land dry climate settled in quite a few regions and continental terrestrial red sandstones were being deposited. In the sedimentary rocks of Devonian age we find deposits of oil of the Russian and North-American platforms, inconsiderable deposits of hard coal, while the weathering of Devonian limestones may well be associated with the deposits of bauxites—the principal ore of aluminium.

The Carboniferous system, or Carbon (350-285 million years), received its name due to the richly propagated deposits of hard coals everywhere in its sediments. It was also discovered in Great Britain.

This period was distinguished from the Devonian system as far as the distribution of sea and land was concerned: after a short uplift in the Carboniferous period there followed the submersions of continents over a considerable area. The sea in the lower Carboniferous period continued to exist within the vast geosynclines, the Ural, Mediterranean and other varieties, which continued to grow. The sea, however, also

spread away from them, to other platforms, and the Russian one, in particular.

The Moscovites can see this for themselves if they carefully watch the slopes of the gorges in the upper parts of Chertanovka—the little river near the Tyeply Stan micro-district. There in the rocks composed of limestones it is possible to discover large and well-preserved thick-walled massive shells of brachiopods. Well, in those days the Moscow region of today was just a sea. What can also remind us of the Moscow Carboniferous sea is the name of one of the brachiopods found in the limestones of the Moscow region and called Spirifer Moskovensis.

In the Carboniferous seas there remained many types of animals that were characteristic of the Devonian period. Others had spread on a markedly wide scale. Intense growth and reproduction were typical of the simplest organisms, such as foraminifers, particularly the spindle-shaped, elongated fusulinas, that looked like grains of barley. At the expense of little shells silts were developed, which were later transformed into limestones.

The leading forms that serve to determine the age of Carboniferous layers include some of the brachiopods, and particularly the Productus Gigantus variety with the thick-walled rounded shells. How these shells helped me in singling out the carboniferous

masses during the geological survey in Fergana! They were practically innumerable in the sandstones—which were a real burial place for brachiopods.

No minor changes had taken place on land. It was the time when forests grew most profusely. The trees of Carboniferous period, with spores serving as the basic form of reproduction, did not have anything in common with the trees we see today. For instance, the sigillarias did not even have leaves. They had a tall stem and on its top a narrow cone-shaped 'panicle' of green emergences which looked more like needles than leaves. But there had already appeared huge pteridospermaphytes and equiseta. The vegetation of wet Carboniferous forests yielded the material for peat and the future largest deposits of hard coal.

The animals inhabiting the land also became of various types. The Carboniferous forests were most propitious for the insects. Among them the Meganeura dragon-fly looked like a giant. Its wing-spread reached 75 centimetres. A host of insects had emerged by that time: cockroaches alone were represented by hundreds of different kinds.

Believe it or not, but as far back
as Carbon,
The cockroaches lived, and we beg
you a pardon,

For letting you know that even today,
And try as we can to suppress
them again,
Our efforts are bound to be only
in vain.

In the Carboniferous period there continued movements of the Hercynian folding with the intrusion of magmatic rocks and the formation of ores. In the Urals iron ore deposits of the Magnitnaya mountain and others originated. In Central Asia and Kazakhstan a large number of the deposits of copper, lead, zinc, and tungsten were developed. Of no minor significance in the Carboniferous masses were the deposits of hard coal and anthracite (Donbass, Karaganda), as well as oil and gas (the Second Baku of the Volga-Ural region).

The Permian system (285-230 million years) received its name from the Perm province in Russia. Its strata were singled out by D. Sokolov, professor of St. Petersburg Mining Institute, and their name was suggested by the English scientist R.I. Murchison, who at that time was travelling in this country.

The Permian period comes at the very end of the Paleozoic era. During the time preceding it and as a result of the Hercynian folding the distribution of land and sea had undergone marked changes. The same could be said of physiogeographic conditions in general. Over a vast area the uplift

of continents took place. This was accompanied by the desiccation of the seas and the formation of large mountain chains. In the Siberian platform there was a regular outflow of basaltic lavas.

The elevation of comprehensive regions brought about the change in climate and the origin of climatic zonality. In the Mediterranean zone, contiguous with the Tethys geosyncline, there remained tropics, while to the north there extended a great arid zone, where continental red sandstones and clays were deposited, as well as salts (in Russia it is the Solikamsk deposit; in Germany this kind of deposit originated in Strasfurt). In the arid zones of Europe true ferns had disappeared within that period.

In the seas of the Permian system animals, similar to those of the Carboniferous period, still existed, though their new forms had also appeared. In particular, what gained a still greater development included ammonites (cephalopods), which later, in the Triassic period, became highly important forms in age distinction.

On land the development of life continued too: there emerged large amphibians and among them such big predators as inostrancevia, as well as the variety that was intermediate between the amphibians and the reptiles, known as batrachosaurs, while the Upper Permian became remarkable for the highest therapsidic reptiles. Some of them

had already acquired the features similar to those of mammals.

In some places the masses of Permian deposits were directly transformed into those of the Triassic variety whose composition had much in common with them. In such cases they are brought out into a single Permian and Triassic series (the north-east of the USSR).

The Triassic system (230 ± 10-195 ± 5 million years) was the first period of the Mesozoic era. Its name was derived from the fact that in the sediments of this system which was discovered in Germany three layers were distinguished.

By the beginning of the Triassic period vast territories had become devastated. The former geosynclines of the northern continent Eurasia ceased to develop further, and mountain ridges rose in their place. The restructuring of the forms of relief markedly changed the composition of organisms, which was precisely the factor that made it possible to keep Paleozoic and Mesozoic eras apart.

The Triassic period was also characterized by the formation of new sea basins around the Pacific Ocean in the present-day territories of the East of Asia and the West of America. It was precisely in these zones that in the later period there emerged the Pacific folded belt. A new kind of folding which received the name of Ancient

Cimmerian manifested itself at the time of the Triassic system. As is assumed, it was then that Gondwana separated into the African-and-Brazilian and Indo-Australian parts with the emergence of the Indian Ocean.

The magmatism of Triassic system is associated with the formation of a large number of ore deposits of the North-American Cordilleras (copper, lead, zinc, and gold) the South of China (tin, tungsten, antimony, and mercury), Asia Minor, Thailand, Indonesia, and Vietnam (tin and tungsten).

The Jurassic period (195 ± 5-137 ± 5 million years) bears the name of the Jurassic mountains in Eastern Europe where its beds were discovered. The ancient Cimmerian tectonic movements preceding the Jurassic period led to the elevation of land and many mountain structures (the Transbaikal region and south-east of China) as well as to the marked reduction of the areas occupied by the seas.

In the Lower Jurassic there was a considerable narrowing of the Mediterranean geosyncline though the geosynclinal basins around the Pacific Ocean which were formed as far back as the Triassic period were widely spread.

In the Upper Jurassic the sea had again been invading the Russian, Siberian, and Chinese platforms. The Upper Jurassic

period was characterized by an established zonality in the distribution of sediments of various composition connected with the climatic zonality: in the comprehensive seas of Eurasia the same masses of sand stones and clayey schists were formed (North-East and the Far East of the USSR), while in the Southern warm Mediterranean zone limestones were deposited. This zone of carbonaceous sedimentation occupied a wide belt covering the whole of Central Europe, the Southern half of the East-European plain (the Russian platform), the regions of Central Asia, the south of China, and Indochina.

Among the sea animals in the Jurassic period, as well as in the Triassic system, the ammonites were widely developed including those that they had already been represented by their other varieties: the bivalve mollusks, marine sponges, sea urchins and corals. But the main characteristic feature of the Jurassic period was the further growth of large saurians. Some of them reached an enormous size. Among them were those living on land (brontosaurs, diplodocus), the swimming variety (ichthyosaurus, plesiosaur), and the flying species (pterodactyl).

It was the time of sea crocodiles and the toothed birds (archeopteryx), which had some similar features with the saurians.

Strange is the pterosaurs soaring
in the air,
Or is the dentate scaly predatory
The product of a nightmare?
It's there that brontosaurus with
tail so huge
Had dried a gully as after
a deluge.
But the pterosaurs we have in
mind
Is huge, herbivorous and kind.
Perhaps its scales that rang with
every move
Pre-echoed my own origin that I
now seek to prove.

The mammals had also appeared. But they were small animals that reminded the rodents we see today. This line of the evolution of animal kingdom developed very slowly: the mammals reached the acme of their development only in the Tertiary period.

The Jurassic period was characterized by the frequent recurrence of tectonic movements and the manifestation of magmatism in the North-American Cordilleras, the Transbaikal region, China, and the Caucasus. The mineral resources that were typical of the Jurassic period included the deposits of coal and various ore deposits, such as chromium, iron, platinum, gold, lead, zinc, silver, antimony and mercury, tin and tungsten, which were particularly widespread in the Pacific ore zone; the Transbaikal region, Malaysia and Indonesia, the coastal ridges of North and South America.

The Cretaceous system (110-70 million years) acquired its name from the beds of chalk in Europe. In the wake of the new Cimmerian folding the areas covered by the sea were reduced, the continental masses expanded, and the geosynclines remained only in the fringing of the Pacific Ocean and the Tethys zone.

In connection with the change of geographical conditions the vegetable kingdom underwent marked changes. The forests, swamps. and meadows received a different shape. Instead of widely spread mosses, equiseta, ferns and coniferous plants the Earth was covered by various phanerogams or angiosperms.

The seas were inhabited by diverse mollusks, including the shells of gigantic size. Ammonites reached three metres. Bony fishes and large reptiles such as ichthyosauruses and plesiosaurus swam in the sea, and at the end of that period there were also mesosaurus the length of which was up to 12 metres.

On land huge saurians were preponderant. They included such large predators as the tyrannosaurs. The enormous herbivorous iguanodonts had also emerged. The pteranodons had their wingspread increased up to eight metres. By the end of the Cretaceous period no minor development had been reached by the mammals—the small animals that had much in common with the pres-

ent-day rodents. The marsupial mammals, which some time later spread in Australia and South America, had formed an individual group beginning with the Cretaceous period.

The end of the Cretaceous period was marked by 'the great Upper Cretaceous transgression': the seas covered a large number of continents, and then on the borderline separating the Cretaceous and Paleogenic periods the sea retreated. The expression of the new—Laramian—folding, which was particularly intense in the Pacific mobile zone. Rapid changes of events: the advance (transgression) and retreat (regression) of the sea could not but exert their impact upon the composition of flora and fauna, which altered most radically at the end of the Cretaceous period. Ammonites became extinct in the seas, marine and land saurians had completey disappeared. This variation of fauna is exactly what serves as the basis for establishing the boundaries between the Mesozoic and Cenozoic eras.

In connection with the Laramian tectonic movements large folded structures of North-American Rocky Mountains and South-American Andes were formed. The same could be said of the folded system in the east and northeast of the USSR: the Sikhote-Alin and Yan-Kolyma-Chukotka systems.

Around the Pacific Ocean, especially its

western part, there emerged great volcanic belts, which extended over thousands of kilometres along the deep faults of the earth's crust. That very period is also connected with the origin of immensely large deposits of various metals in the fringing of the Pacific ocean and the further development of the Great Pacific ore zone with rich concentrations of gold, silver, copper, tin and tungsten, lead and zinc, antimony and mercury.

The Paleogene (67 ± 3-25 ± 1 million years) is divided into three sections: the Paleocene, the Eocene, and the Oligocene. In many respects this period is distinct from the preceding Cretaceous period. At the time when Laramian folding found its expression the areas occupied by the sea became markedly reduced and the terrestrial belts along the large fractures of the earth's crust received further development. However, at the extreme east of Asia (Sakhalin, the South of Japan, the Philippines) and within the Tethys zone (the Caucasus, the Carpathians, and the Alps) the development of the belt of the earlier deposited geosynclines was still in progress.

The animal kingdom experienced a marked change in the Paleogene period. As has already been mentioned, the saurians which inhabited the Earth for over 200 million

years had become completely extinct. What could possibly have accounted for it? Catastrophic cosmic phenomena? Changes in vegetation—basic means of nutrition?

The mammals continued to develop more rapidly. In the Eocene there appeared predators, ungulates, rodents and insectivores, while in Africa the first proboscideans and apes emerged. The fauna of Australia with its peculiar complex of marsupials developed on its own: Australia had already been separated from other continents by the seas. According to Academician A. Yanshin, at the beginning of the Eocene South America, where the relatively primitive fauna of marsupials and monotremes originated, separated too.

The vegetation had acquired the features comparable with what we can see today, though a large number of relic pertinent to the Cretaceous floras had still been preserved on its composition. Its geographical distribution was different from what it is now. For instance, in Western Europe, Middle Asia, Kazakhstan and even Chukotka tropical and subtropical forests with evergreen palms, magnolias and many other plants, which are now found only in tropical and subtropical zones of the world, grew in the middle of the Paleogene (Eocene) period. The climate was warm and humid. All this was highly propitious for the accumulation of the material that was required for

the formation of large reserves of coal.

At the end of the Eocene period and on the boundary with the Oligocene there took place a marked cooling (the temperature of the water in the World Ocean became 5-6 °C lower), which also brought about a drop in temperature in many parts of the land. The evergreen plants gave way to the deciduous ones. But at the end of the Paleogene the temperature had again become somewhat higher.

The Paleogenic deposits are connected with oil and combustible gas (the Northern Caucasus, the Carpathians, and California), while the magmatic rocks may well be associated with the deposits of a large number of metals, particularly in the Pacific ore zone: tin, lead, zinc, copper, and molybdenum. This period of ore formation was a direct consequence of the Upper Cretaceous or Lamarian period.

The Neogene (25 ± 1 million years), which is classified into the Miocene and Pliocene periods, is marked by an enclosure of young geosynclines and the formation of the folded zones of the Caucasus, the Alps, and the Carpathian mountains, as well as the elevation of the ridges of the Tien Shan and the Andes in blocks, and the formation of the folded belts (New Guinea).

At the beginning of the Neogene the temperature rose to a considerably high level;

in Central Europe, for instance, palms and other evergreen plants began to grow. A comparatively warm climate was also typical of the Eastern part of Asia, which was remarkable for the flourishing of broad-leaved trees. By the end of the Neogene they were replaced by the cold-living conifers.

In A. Yashin's opinion, the fauna of the Neogene period had already much in common with our own: there appeared the ancestors of the contemporary bears, dogs, as well as hyenas, proboscideans (mastodons), gigantic tigers, and tridigital horses. In South America, which had remained isolated from North America until the middle of the Miocene, there burgeoned a specific kind of fauna of gigantic edentates, marsupials, ungulates and platyrrhines. In the middle of the Miocene, however, a connection was established between the two Americas, which resulted in that a more highly developed North-American fauna penetrated into South America. The marsupials had become extinct here. They remained only in Australia. Some of the Australian marsupials reached enormous dimensions.

The fauna that was spread in Europe and Asia, however, was that of steppe type, and the herbaceous steppes were pastures for the herds of tridigital horses, or the hipparions. But the most important event of the Neogene was the advent of Man!

The Neogenic sedimentary masses (the Miocene) are correlated with the oil deposits of Azerbaijan, Turkmenia, Sakhalin, Iraq, Iran, Roumania, Mexico, and Venezuela. Some of the marginal seas must have originated in the Miocene period too.

The borderline between the Tertiary and Quaternary periods has not yet been established. The Quaternary period was called Anthropogen, assuming that it was the period when anthropoid (man) emerged on Earth. But the time when man first appeared has not been determined with any degree of exactitude, and with the new discoveries goes even further back into the ages. The finds of anthropoid beings (of man rather than of apes) in Africa are as old as more than four million years.

Thus the boundary between the Quaternary and Tertiary periods had to consequently go down too. If only recently the beginning of the Quaternary period was taken to have been 500 thousand or one million years, today this most important landmark in the Earth's history is lowered to 4.2-3.8 million years. New discoveries and special research of the remains of our ancestors with the help of numerous methods help to specify the said border.

And yet the question pertaining to the time when man emerged remains highly important. The advent of man is closely related to the appearance of new geological proc-

esses—the artificial change of the Earth's landscapes, the development of new forms of animals and plants, and above all an intense transformation of the planet into regions known as the noosphere.

The characteristic feature of the end of the Quaternary period consists in numerous cases of glaciation, which were replaced by spells of warm weather in the interglacial time. With the warm periods there took place the thawing of ice and the elevation of the World Ocean level. During the cold periods the animals accommodated themselves to the drop in temperature: there emerged, for instance, woolly mammoths and rhinoceroses.

In the Quaternary period there was also the migration of plants and animals, and then the people across the Bering bridge from Asia to America. It is precisely the income from Asia that the origin of American Indians finds its explanation.

What was it then that determined the change of living organisms—the foundation of historical geology? The periodic rises in radioactivity? Could the influence upon the development of life have been exerted by such a catastrophic event as the assumed explosion of the Phaëton planet? It is of no minor interest that in the Cambrian beds themselves we find a large amount of vitreous globules, or tektites, which might have emerged at the time of the burst and were

poured down upon the Earth. Suffice it to say that this period is marked by a genuine revolution of the animal kingdom—a comprehensive development and propagation of animals, covered with an armour and hidden by shells. To what extent was this event connected with the phenomena, that were taking place in outer space, or was it merely reflecting the transition from quantity into quality—the attainment of a particularly optimal composition for this kind of development of organisms of the hydrosphere?

But the evolution of the living world itself had conditioned the change of both the atmosphere and the hydrosphere. Oxygen, as the product of the activity of plants, gave rise to a protective ozone cover of the atmosphere, which, serving to guard against the ultraviolet rays that are hazardous to it, had enabled life to come out onto the land. This was a new and most tangible advance in the development of the biosphere.

Part III
Geology Everywhere

The changes that the Earth has undergone in the course of its development have just been briefly discussed. In different regions and parts of the USSR their character was by far not the same.

The inhabitants of Leningrad can imagine the most ancient period, when 2-3 billion years ago at the place of their houses there raged tempestuous elements and volcanoes like a host of torches burnt under the lowering clouds impregnated with volcanic gases themselves. Then the titanic forces crumpled the ancient layers into folds and Cambrian blue clays and Ordovician limestones were deposited upon the surface that was made even.

Those who live in the districts close to Moscow can watch the traces of more recent events—the intraplatform seas of the Carboniferous, Jurassic, and Cretaceous periods which are witnessed by the fossilized shells in the limestones.

Traces of various processes can be seen by people in Central Asia: the sediments of Paleozoic geosynclinal troughs, the formation of mountain ridges and their destruction, the deposition of continental red sand-

stones and clays in the depressions, the coals in the Upper Jurassic-Lower Cretaceous periods and the new advance of the sea in the Upper Cretaceous-Paleogenic periods with the formation of limestones. And lastly, in the Neogene—the new elevation of the higher mountains of Tien Shan with their snow-covered peaks. It may sound incredible, but all those events did take place within the territory now known as Central Asia.

Even quite close to where they live the Far Easterners can see layers of sandstones and schists crumpled into sharp folds. These beds originated from sands and clays that were deposited in the seas of the Permian, Triassic, Jurassic, and Cretaceous periods. And what is most important is to try to visualize the enormous volcanic belts of the Cretaceous and Paleogenic periods when many hundreds and thousands of volcanoes erupted, the lavas outflowed, hot ashes fell out, and volcanic masses of several kilometres thick were formed.

The inhabitants of Kamchatka are born geologists. Right before their eyes they have the activity of volcanoes, eruptions and earthquakes. The interiors of the Earth live and breathe; at their hearth Pluto has not yet been calmed. This perpetual change of events is the sum and substance of geology.

We have been dealing with the processes of the remote past—the history of the

development of our planet. But the geological processes do go on and we see their traces at every step: it is the activity of water, wind, and the deep-seated forces of the Earth, that find their expression in earthquakes and volcanism. The study of contemporary geological phenomena also help to understand the processes of the remote past. As years and years ago there now continue to act upon the Earth the most important gods: Aeoulus—the god of the winds, Neptune—the god of the seas, Pluto—the god ruling over the lower world and his assistant, Volcano—the god of subterranean forces. Their struggle results in the processes of destruction, transformation, and creation of the earth's crust. These processes are within the domain of physical geology.

Chapter 7
The Work of the Wind

Aeoulus—the god of the winds must be the oldest of all the gods since it started to act at the time when the Earth was only beginning to develop. The wind manifested itself even in the protoplanetary stage, when due to the difference in temperatures whirlwinds of cosmic dust moved from one place to another along the surface of the Earth.

Over the long history of the develop-

ment of the Earth huge masses (many millions of cubic metres) of volcanic outbursts have been accumulated. In their transportation in the air no minor role was played by the wind. In the descriptions of the contemporary eruptions we find the information concerning the transportation of ash and petrified splashes of ejected lava over the distance of a large number of kilometres. The paths along which the ash clouds fly depends on the change in the direction of the winds.

In 1973 I happened to witness a complicated dislocation of ash during the eruption of the Tyatya volcano in the north of the Kunashir Island of the Major Kuril arch. From the very beginning of the eruption a black mushroom-like cloud rose above the volcano out of which ash was falling out. At first it was greyish, and then black. The wind drove it to the south of Japan, and then the cloud went back towards the islands of the Minor Kuril arch. All the islands along the way of its itinerary were covered with a thin layer of black ash.

The transportation of volcanic material in the air took place many times in the history of the Earth. In the regions of past volcanic activity, as, for instance in Primorye, where in the Late Cretaceous period volcanoes were functioning most actively thick masses of tuffs were concentrated.

They were formed from the volcanic outbursts scattered by the air over vast areas. The thickness of these masses that mainly fill the depressions of the ancient relief reaches several kilometres.

But in those places that are quite remote from the volcano it is also possible to watch the activity of Aeoulus: the transposition of dust and sand by the wind. Hurricanes—dry winds—dry out the soils of the fields. The winds move the sands from one place to another in the deserts, and deflate large depressions upon the Earth's surface.

The elevating power of the wind is very high. It rises with the increase in the velocity of the wind: at the rate of 20 metres per second the wind transports sand and gravel. When the velocity reaches 30 metres—the wind carries away small stones and roots out the trees. On some occasions I saw how during the fires the hurricane wind threw torches of burning trees over hundreds of metres across the valleys.

In 1983 in the eastern part of the United States there was a catastrophic hurricane the velocity of which reached 220 metres per second. That same year India witnessed a 'downpour' of fresh water fishes (!). It is assumed that a tornado had pushed them out of the water bodies. It was mentioned earlier that it had also rained frogs and silver coins.

On June 9, 1984, hurricane winds, and in some areas unprecedented tornadoes, which brought about destructions and casualties covered the territory of 18 regions and autonomous republics of the RSFSR.

On the whole storms are by far not a rare phenomenon. According to the data provided by Academician D. Nalivkina, over the period of four years (from 1951 to 1955) 3882 storms raged on Central Asia.

The comprehensive deserts only seem to be immobile. Sand ridges, or barkhans, are always in motion there. On the crest of the barkhans, which can be as high as 70-100 metres, the quicksand winnowed by the wind eddies incessantly, And these crescent-like hammocks are all the time being transported, and driven by the wind, with masses of sand moving after them.

The light dust particles are transported by the hurricanes in dust clouds over enormous distances. For instance, masses of dust from Sahara reach even the Russian platform. It is assumed that it had been precisely this way that from a mass of fine particles transported by the air there used to emerge masses of loess—the compact yellowish rock of the Quaternary age. In China the thickness of the loessial beds reaches 170 metres.

The eolian sands are also widely represented on the coasts of the seas. They are

called the dunes. They also move under the powerful pressure of the wind. The rate at which the sand travels in the dunes is between several centimetres and 20 metres. The dune ridges themselves can be as high as 200 metres.

One cannot but also mention the destructive activity of the wind. Together with the other surface agents, mainly water, it plays a substantial role in the destruction of the stone rocks. It polishes the stones with the blows they receive from myriads of sand grains, and blows out the friable parts of the porous rocks, which are then carried away into the sea by the waters of the rivers. It's no wonder that the geologists call the process of the destruction of rocks on the surface weathering. In the course of the latter's activity the rocks are fissured and there appear tall columns of whimsical form, particularly characteristic of granitic rocks. At the foot of the rocks we can see the accumulation of rock debris and sand. And thus the sands move on threatening even the places of human habitation.

I was only a little girl when we came to Central Asia to a station that was to irrigate the desert. The station was situated at the edge of the Hungry steppe, which was spread right before our house—the boundless, lifeless piece of earth covered with fine yellow quicksand.

The morning was very bright. The Sun

was shining in the blue sky in all its splendour. There was nothing that could portend a storm. And yet all of a sudden there was a gust of wind and everything went dark brown behind the window. The sand got into every chink and hit hard against the window panes. Mother tried to open the door but closed it almost immediately. Her mouth, nose, eyes and ears were in sand. The kerchief was blown off from her head by the wind. We found it afterwards at the distance of several kilometres from our house.

Then the sand storm ceased its activity leaving in its wake ramparts of sand at the walls of houses and fences. The sun shone brightly once again in the serenely blue sky.

Now, quite recently I happened to visit Africa, and there I saw the work of the winds with my own eyes. The gigantic temple in the ancient Egyptian city of Luksor, which was built in the days of Pharaohs, was at one time completely buried by the sand, and on this sandy hill the Arabs built a mosque. It stood on the stone plates of the roof of the ancient temple as if it were the foundation itself. Today the temple has been excavated and appeared before the eyes of its beholders in all its monumental splendour. It remains a mute witness of the power of the wind in the desert.

Only a miracle can account for the fact that my mother's pupil Ronya Vasilev-

skaya, student of the Central Asian University who was having her student practice at the research station in the desert after losing her way amidst the indistinguishably 'undulating' barkhans managed to get back to her team. She could hardly differ one barkhan from another and for three days could not find her way back to the station. All quests were fruitless since the sand did not leave a single trace intact. She had found her way back herself! It was only the exclusive will-power and persistence of the then only a young girl Ronya (later known as Veronika Kazimirovna Vasilevskaya, professor of Leningrad University) that saved her life in the desert.

Nowadays large expeditions of geologists, geodesists, biologists and archeologists carry on their work in the deserts.

What helps to orientate in the desert is the maps compiled according to aerial photographs. The aerial photographic survey allows the scientists to discover the features of ancient structures, castles, walls of fortresses, channels, riverbeds and watercourses of former rivers, as well as the traces of what used to serve as caravan paths. A small shadow on the photographs taken in the desert at the time of the gloaming makes it possible to distinguish the blurred contours of the structures that do not lend themselves to terrestrial observation. This is followed by excavations, which are bound

to unravel the mysteries that lie behind the ancient habitation and ever-alternating epochs in the development of culture: many hundreds of fortresses, cities and ancient irrigation ditches have been discovered in this way. A good example of this is the vast Khorezm kingdom of oasises.

The archeological expeditions of the corresponding member of the USSR Academy of Sciences S. Tolstov and his colleagues did a sufficient amount of work to reconstruct not only the geography of the habitations buried under the sands, but also the history of the development of culture in what is now a lifeless extensive zone of the deserts.

Population areas of various epochs are now covered by the sand. Why did they perish? Was it their internecine wars? The invasion of enemies? . . . or the encroachment of the desert?

But often the desert had only completed the destruction of those places where people lived. The sands buried the once inhabited areas when the latter were totally neglected by people after the inroads of the enemy or during the migration as well as the desiccation of riverbeds and the watercourses. As is known the Amu Darya had left its riverbed Uzboi. In the past it had issued into the Caspian Sea, and later receded from it and found the way to the Aral Sea on its own. The change of a riverbed implied the destruction of channels, with people leavin

their homes, and the desert continuing its advance.

However, the sands did not only destroy people's homes by burying them. They have also preserved for the coming generations the past structures that help to recreate the great history of this comprehensive desert region.

It is now common knowledge that Central Asia had its own centre of the advent of Man. This is testified by the find of Academician A. Okladnikov who discovered the remains of a Neanderthal boy in the cave of Teshik-Tash. Systematic excavations undertaken by the archeologists establish several periods in the development of culture.

The earliest of them was the Neolithic period (the late Stone Age—the third millenium B.C.). All the population of the tribe (family?) lived in one tent-like house on the bank of the Amu Darya River. The house stood on the top of a barkhan (now its form is being reconstructed by what is left of the structure). The house was inhabited by hunters and fishermen, who were making tools of stone and bones.

The new period was the Bronze Age. It was marked by the domistication of animals (two thousand years B.C.). Cattle-breeders were building long houses, and then huge square enclosures for the cattle. The people themselves numbering several

thousand all in all lived in the galleries in the middle of the thick walls of the square enclosure, protecting the cattle from the encroachments of the nomadic tribes.

The brilliant antique stage refers to the eighth-sixth centuries B.C. It was remarkable for spacious urban development, the construction of enormous canals with their ramified network of irrigation ditches. The cities were surrounded with vast fields and gardens, and the oasises themselves were secluded from the rest of the world by very high walls. Large and very high structures that are as tall as our five-storeyed houses and even taller are now relieved of the sand drifts and appear before our eyes in all their magnificence. That was the time of the great Khorezm empire, the influence of which was spread even beyond the Urals. The caravan path connected it with the Western countries as well as with the Eastern ones (China).

And how, for instance, were the walls of the monumental urban ensemble of Toprak-Kala discovered? They were completely buried in the sand. The wind had been drifting sand to them for the period of fifteen hundred years, and there emerged a sandy rampart, in the contours of which only the experienced eye of an archeologist could detect the traces of regular artificial constructions. After the excavations were completed the archeologists beheld a mira-

cle of ancient architecture—a tall castle with the dwelling houses for large families (generations) together with the preserved sculptures and frescoes.

The excavations also reveal the ensuing pages of the history. Uplifts alternate with downfalls. The distintegration of the slave owning system and the transition to a more progressive Feudal regime, though at the same time the fracturing of the country, the decrease of irrigation structures (there were now no slaves to dig and maintain the channels), the slackening of the ties between the feudals and the invasion of the Arabs that had conquered the countries of the Central Asia in the seventh-eighth centuries A.D. found their coherent expression.

The new stage in the flourishing of civilization of the early Middle Ages (the period between the eleventh and the twelfth centuries) was connected with the appearance of large cities, the scientific schools of Biruni and Ibn Sina as well as the new fall brought about by the incursion of Genghis Khan. And all these events have been reflected in the architectural monuments, which were hidden by the mute sands of the desert. Those who succeeded in reading the soundless record of those events were our archeologists.

But the research carried out by the archeologists does not merely penetrate into the past. It is also a key to the future.

Along the traces of the ancient irrigation ditches, channels and watercourses the water flows again to bring life to the desert. Along the dry Uzboi, the ancient riverbed of Amu Darya, the great Kara-Kum canal is being built and the dead sands give way to new oases and cities.

This is how the poet V. Berestov puts it in verse:

The traces patching the barkhan
And the dried riverbed of Daudan
Hear the mice squeak in a sandy mould
And watch the violet tamarisk unfold.
And slender shadow is cast by the bush so thin
With only desert lilac smelling of the dust within.
While we are walking through the inspissated sultry air
Upon the land scorched and made bare
So that the river could be brought back to the Earth
And flowers knew no fragrance dearth.

Chapter 8
The Role of Water in the Transformation of Our Planet

The water is even more powerful than the wind. In the transformation of the crust its function can hardly be overestimated. No little changes does the work of the water bring on land, where the washout of rocks is practically incessant. The role of water is

particularly significant in the transformation of the relief. The water cuts deep valleys and washes out very high mountains. Suffice itto say that there exists such a saying as this 'continual dripping wears away a stone'.

The destructive activity of water can be seen not only in the mountains, where the strong streams carry boulders and pebbles —the products of washout of hilly rocks, but also on the plains. There the work of water finds its expression in the formation of gorges—the enemies of our fields.

Everything takes place within a very short period of time. At first we have the rain channels, which emerged at a small slope of the surface at the time of the fresher, then there is a narrow little valley, the head of which moves onward and penetrates into the plain ever deeper. During the flood little streamlets come down the slopes of the valley and there emerge lateral tributaries. The gorge begins to ramify and already covers a considerable area, while the plain is split into valleys and elevations. Isn't it a fact that the so-called mountains of the plain regions are most often actually the result of the washout of the surface by water streams and little rivers.

This can be illustrated with the help of an example of Chertanovka, a very small river which begins its flow in the springs of

one of the Moscow districts. Within the period of many years this small river cut itself such a deep valley that its steep slopes have now become real mountains. They serve as one of the favourite skiing tracks for the Moscovites. The river had first made its way in the friable underlayer, and then cut into the bedrocks. In some places we can see real hills on the slopes. And so the people in Moscow can study geology in the scarps of its valley and knock out shells of the Carboniferous age from the limestones.

What then can be said of those who live in the uplands? I have already said that in my school days we studied the geology of the neighbouring districts of Tashkent. And throughout all the mountain regions, be it the Transbaikal region, the Far East or Central Asia, the young researchers can acquaint themselves with various geological phenomena, and primarily with the activity of the rivers in developing the present-day relief and making it more complicated.

Speaking of the destructive work of water in the foothill regions, we cannot but mention the mud flows, or streams of semiliquid clayey mass which fall upon the people's settlements along the river valleys. I can still remember the mud flow in Alma-Ata on July 8, 1921. A small river called Almaatinka, flowing across the city, had been followed by a mountain creep in the

upper part. Under the pressure of water the dike broke and along the valley there flowed a thick clayey mass which carried with itself a large number of stones. This avalanche of semi-liquid clay broke into the city and flooded its streets.

What I remember from the days when I was only a little girl is that everybody was terribly frightened by the growing waves of a thundering sound. It was first taken for an artillery fire, while actually it was produced by the huge blocks of stones that were as large as a truck and even greater. And only when the people who owned the house where we stayed could pull themselves together, they peeped out into the street through the chinks in the shutters to see that from the windows of a house that stood on the opposite side of the street there issued a thin band of golden light. It was the reflection in water.

We heard the cries: 'Help! Help!' followed by a knocking at the gate. It then occurred that a house turned across its axis was standing in our street. Since the houses there were chiefly made of logs, the water pressure could easily take them off their foundations and they floated together with their inmates like toy-ships along the streets that now looked like rivers.

The level of the ground in the city rose one or one and a half metres up and the windows at that time became directly con-

tiguous with the layer of a hard clayey mass. The huge stones welded into the clay had for many years been cleared away from the streets. As was estimated later, the overall amount of the removed material was 3250 cubic metres. Preponderantly it was the clayey mass, and about 7 per cent was accounted for by large fragments and lumps.

No little work is done by the underground waters that feed the upper part of the Earth's cover. They make way for themselves along the layers of porous rocks saturating them with moisture, flow along the fissures in the same way as subterranean rivers, dissolving some of the rocks, as, for instance, limestones, and give rise to innumerable labyrinths and enormous hollows, or caves, with lakes within them.

As a result of the depletion of underground waters that had been pumped for water supply purposes, there occurred a collapse of rocks and the formation of huge sinks in the southern parts of the United States of America. In addition to this whole houses were partly subsided into those depressions. I can still recall a story about what happened in one of the ore regions in the south of China when on a certain occasion trucks fell into the voids among the limestones as though it were an abyss.

No minor changes into the landscapes are brought about by the floods. I remember a huge elevation (more than 5 metres!)

of water in the Amur River in 1981 when its left bank was flooded over a vast area. The water engulfed the whole settlements, leaving after its recession only a layer of mud in the fields.

The floods of the great Nile had annually conveyed the wide valley with the most fertile silt. It was precisely owing to the Nile that the ancient agriculture could flourish in the country. Today, however, that river's run-off is regulated by the Aswan Dam and the silt is now brought to the fields in carts.

Not only the mighty rivers, such as Amur and Nile, but even the very small ones are turned into tempestuous streams at the time of heavy rains. Thus, in Vladivostok, where the river valleys seldom exceed 10 kilometres, during the floods masses of water with stones drawn by them fall upon the lower parts of the city. Over the period of only several hours the water washes a new layer of fragmental material—clay, sand, and stones—which is as thick as one metre and more. Great is the power of water!

The calamities brought about by water are highly varied. Inundations sometimes acquire the form of catastrophic deluges. Let us recall the stories existing with all the nations and religions about the so-called Floods. Devastating floods did take place more than once. There is every reason to believe these legends! Suffice it to say

that about 10 thousand years ago after the thawing of the glaciers the water in the World Ocean rose to the level of almost 100 metres, which was exactly one of the Floods we speak of today.

The advance of water upon land also takes place at the time of the so-called tsunami—a huge wave, which rises in the ocean after the earthquakes and rushes on the continent, actually 'erasing' everything that it meets its way. I happened to watch a small tsunami in the Far East in 1940, which though considered to be on a less impressive scale, remained indelible on my memory. Motor-boats were thrown to the shore about one kilometre away from the sea. The waves brought a large amount of fish which was loaded into the carts. It was most fortunate for the fishermen, though one could not but feel sorry for the fish. A catastrophic invasion of tsunami befell the town of Severo-Kurilsk, which was practically washed away by the waves in 1956. Seiners were thrown out of the waters by tsunami in May 1982. The height of the waves in the Kuril Islands reached three metres. The inhabitants were warned beforehand and nobody was hurt. The tsunami service is on duty all the time.

People struggle against the sea, thus protecting the land and reclaiming new territories from the deep. This war has been going on incessantly in the low countries, such as

Holland. After all one third of the country is the land that has been reclaimed from the sea, and it is separated from it by dams.

I once travelled in Holland, and what comes back to mind now is the road amidst the green meadows in which the cows were serenely grazing, and the boats were floating and the waterways whose dams are raised to a level higher than the land. Against the background of bright-green grass the windmills are made even more prominent. These remnants of the past do not merely perform an ornamental function, but are also active ingredients in the system employed to drain the subsided plain. With the help of the wind their vanes disperse the fogs. In its time this fact did not escape the notice of Karl Marx. Now, in conditions of the current energy crisis the efficient Dutch are thinking of using the power of the wind to receive the electric energy.

The war that the Dutch have been urging against the sea has been going on for thousands of years. The Roman geographer Pliny the Elder mentions a custom of the inhabitants of the coastal zone of the North Sea who settled on the artificial islands, which are tens of metres higher than the sea level. We also know that ramparts protected the low Holland from the sea in the thirteenth century.

The dams in Holland were severely damaged by the bombs during the Second

World War. In 1953 the four-metre rise of water above the usual level again brought about the flooding of vast and densely-populated littoral plains.

The sea also advances upon the land at the time of tectonic subsidences of the coastal lowlands. In Japan I saw the gate of a temple that was submerged into water over the distance of more than 100 metres away from the shore. It was the result of what happened many centuries ago.

Water does not only perform its destructive functions. It is also a great benefactor. In water basins masses are deposited out of which there emerge sedimentary rocks. Water destroys hills of hard rocks, drags boulders, pebbles, sand and silt along the bottom of the rivers, deposits some of them in the shoals and spits, but in the main delivers them to the sea, where the fragmental material is heartily received by the sea waves, which wear it away, fracture and sort it. We watched a high velocity with which the fragments were eroded by the sea waves at a stone quarry on one of the islands in the Sea of Japan. The little granitic cubes that were sawn for construction purposes twenty years agohave acquired globular forms (like footballs) under the activity of the waves.

The tidal and storm waves destroy rocks and form rain channels in them along the fissures. Such rain hills then divide the

stone columns, or pillars of whimsical form. They can often be seen on the sea coast. Along the fissures sea water builds caves, tunnels, and arches in the coastal rocks.

Speaking of the activity of water on the Earth's surface we cannot but mention the work of the glaciers. As everyone knows, the Quaternary period was marked by a drop in temperature, and the ice spread far beyond the present-day polar region. It covered about 30 per cent of all the land and 4 per cent of the ocean surface—the area, three times greater than the contemporary polar glaciers. The thick sheets of ice moved over big distances (up to 48 parallel) and carried huge boulders upon their surface. After the recession and thawing of glaciers these boulders—the strangers from the far North (the geologists call them exotic) can be found in the Baltic Regions, in the fields of the Leningrad region and other northern territories of this country.

In the Quaternary period there were several glaciations which were divided by the interglacial stretches of time. The ice was now advancing, now receding. In the period of glaciations there took place a considerable drop in the World Ocean level, which had substantially disrupted the contours of the land and sea. It was not infrequently that the land bridge, the so-called Beringia appeared between Asia and Ame-

rica. At that time Eurasia and Laurentia (America) were transformed into a single gigantic continent known as Laurasia. Today at the place of what used to be Beringia, the Bering and Chukchi seas are so shallow that measure only 45-60 metres in depth. It can be taken for granted that during the period of the subsidence of the ocean floor to the level of 100 metres, which was assumed to be typical of the latest glaciation, it was most evidently a territory occupied by land.

Traces of ancient coastal line and flooded valleys have been found under the waters. Beringia extended from north to south from the Wrangel Island to the islands of the Aleutian Arch over the distance of more than 1500 kilometres. Along this spacious bridge which emerged within the period of each glaciation, there took place land migrations of plants, animals, and man from one continent to the other.

Nowadays the study of Beringia forms a special branch of science—Beringology, which is developed primarily by glaciologists, as well as geographers, oceanologists, biologists, anthropologists, and those specializing in the domain of the Quaternary geology. The problem of Beringia has become the subject of special conferences and international symposia. One of them was organized in Khabarovsk in 1976.

Even today glaciers are spread over the

vast areas of polar countries. In the Antarctic region a thick glacial armour has integrated a large number of islands.

We can see the contemporary glaciers far away from the polar regions upon the high mountain ridges, where they form ice streams, that creep down along the valleys. In 1929-1930 I was fortunate to participate in the first Soviet expedition to the Pamir whose task was to investigate the Transalai region and the one named after Peter the Great. In addition to geological studies the expedition was to help the mountaineers N. Krylenko and Ye. Abalakov, who was a young man at that time, in their preparation to storm such heights as the Lenin Peak and the Peak of Communism. The paths leading to the tops of those mountains lay through the ice streams, or glaciers, and it was necessary that their practicability should be determined. Besides the then known large glaciers, such as the Fedchenko glacier that extended over 70 kilometres, the Mushketov and Tanymas ones, there are quite a few small ones there, which prior to the 1929-1930 Pamir expedition had not even been plotted on any map.

What I remember very clearly today is the gigantic glacier Fedchenko whose long and wide tongue was coming down along the tub-like valley of the Seldara River, thus ploughing the way for itself within it. Upon the surface of the glacier there was

a host of black latitudinal bands. They were the surface moraines that emerged at those places where the glaciers coming from numerous tributaries coalesced. Now, the Tanymas glacier was bright and sparking with icebergs and pointed spires or 'peaks'.

Our chief glaciologist was Rogov. He was responsible not only for the observations of the glaciers, but for determining their accessibility for the mountain climber. His assistants were only very young people. If we did not do any research on our own, we at least tried to discover the glaciers in the upper regions of the rivers that were tentatively designated on the maps by means of blue dotted lines. We marked the terminal moraines, and where it was possible, we would climb upon them with all the temerity pertinent to our young age. My friend, a worker from Leningrad factory, an enthusiast and dreamer, once fell into the fissure and only thanks to his momentary reaction of a sportsman he managed to get hold of the edges of that fissure and thus save himself from fumbling down into that abyss. But at the time of our next expedition—in 1930—this wonderful young man was killed while fighting against the bandits (basmachi).

It was then that calamity awaited not us, but Fyodr Rogov himself. Together with me, as his assistant, he was crossing the Muksu River to ascertain the position of the

terminal moraine of the Mushketov glacier. He intended to make that place and meanwhile to determine whether it was possible for the mountain climbers to approach the Peak of Communism.

He was very interested in the glacier, and we stayed there for quite some time. But he did not risk to prod the river on horse back—he was short-sighted and could not see very well at night.

We spent the troublesome night by trying to warm ourselves under the saddle-cloths. Then the wind started to blow; it was raining heavily, and in the morning we did not recognize our familiar Muksu River; its waters were now overflowing the vast valley. Our attempt to cross the river ended with the tragic death of Rogov. His diaries together with the notes of the Mushketov glacier and information records about the discovery of other glaciers, which had been brought to him by his young assistants, were found later in the pack that was tied to the cantle of the saddle. They were used in the report of the chief of our expedition, as well as the mountaineers. Those materials also proved useful to the frontier guards who were then fighting against the bandits (basmachi).

Upon the high terrace of the Muksu River we made a hillock of stones and had a board attached to it bearing the name of glaciologist Fyodr Fyodorovich Rogov who per-

ished in the waters of that river on the day that was inscribed therein.

I watched the other glaciers from aboard the plane, flying over Greenland, where in the light spots of the Moon there sparkled ice-covered hills and precipices. I saw exactly the same sparkling fields of ice when flying over the Himalayas; the heart was beating more rapidly as it seemed that the plane was bound to crush upon the huge masses of ice.

In mountain regions ice, just as water, transports the stone material, and sometimes even the precious minerals. Thus, for instance, large marine places in Alaska emerged at the expense of gold that had been brought by the glaciers to the sea.

Chapter 9
The Activity of Subterranean Forces

I spent my childhood in Central Asia, where small earthquakes were not infrequent. People got used to them, and children found them even interesting. During the earthquakes we usually ran out of the house.

I have never been through a catastrophic earthquake myself, but I can hardly describe how my heart ached at the sight of the dilapidated old Tashkent years after that. The city experienced the most violent earthquake of 1965. Fortunately, the number of victims was low; neither were there

any damages, but the houses did crack and whole blocks and districts had to be pulled down. It was strange to see a tram rolling along a green field and to distinguish the contours of the former streets by the rows of pyramidal poplars that once grew close to the pavements. It took me some time to find my girlfriend among the victims who now lived in tents. One of my acquaintances showed me a collapsed corner of the dwelling house, where, fortunately, the children's beds remained intact since they stood by the other side of the wall.

I can still remember the reminiscences of those people who lived in Vernyi (Alma-Ata) at the time of the 1911 earthquake. The number of victims was very great. From various publications we know that the earth was tremoured over the vast territory even outside that city.

Geology is really *everywhere*, and we learn quite a lot about the current processes from our own experience rather than from books.

I. Rezanov in his book *The Great Catastrophies in the History of the Earth* adduces the information concerning the most prominent earthquakes of the world.

The Tokyo earthquake of 1923 proved to be the most devastating one. Tokyo and Yokohama were most severely damaged. The tsunami wave that rose to the height of over 10 metres fell upon the coast and accom-

plished the destructive work of the subterranean forces. About one million people were left homeless and 100 000 were killed.

The energy of Himalayan earthquake in 1950 was compatible with an explosion brought about by 100 000 atomic bombs! Pluto got really angry! The earthquake resulted in collapses and landslides with the volume of the dislocated mass of up to 2 billion tonnes. In the Brahmaputra valley, at the distance of 100 kilometres from the Himalayas, cars were thrown 800 metres back. The earthquake was accompanied first by a hum and then a thunder. Near the centre of the earthquake people could not properly stand on their feet, while one hundred metres away from it they had the same feeling as though they were in a stormy sea.

The consequences of the 1957 Gobi-Altai earthquake were studied and described by the corresponding members of the USSR Academy of Sciences N. Florensov and V. Solonenko. They marked on the maps deep gaping faults and established the dislocation of the rock masses along them. This was where a whole mountain mass consisting of several blocks moved away from its original position. The overall area of the mountain ridge dislocated by the titanic forces was 1.5-3.5 square kilometres. The horizontal dislocation of the ridge comprised tens of metres, while vertically it was up to

328 metres. The said dislocation was accompanied by great downfalls, and in the flooded valley two lakes were formed.

The catastrophic earthquake of 1960 destroyed many coastal cities in Chile—a huge strip of land along the shore measuring up to 20 kilometres in width and 500 kilometres long went two metres down.

In most cases earthquakes take place in the young folded mountain regions, in the seismic zones of the Pacific Ocean and the Mediterranean Sea, which are known as active processes of folding and orogenesis. It has been established that the hearths (epicentres) of earthquakes, which reach the depth of 700 kilometres, are found to be within the limits of zones inclined to the continent, which have received their names from the researchers Zavaritsky-Benioff, who had discovered them.

Within the confines of the Pacific zone of high seismicity a large number of volcanoes are situated. Earthquakes also occur in those regions where there are no volcanoes, and in the zones of ancient folding. In these areas, for instance in Tien Shan and along the mobile Baikal zone, tectonic processes have recurred after a long period of rest.

The eruptions of volcanoes are not less jeopardizing than earthquakes. As has already been mentioned, volcanism had been the main acting force since the time our plan-

et came into existence. However, the forms of volcanic processes have undergone various changes. Initially this found its expression in the overall melting of the thin earth's crust. Then, with the development of a fairly stable and thick crust, the volcanoes emerged along the fissures, thus giving rise to volcanic belts and ridges.

In the archipelagos of volcanic islands there took place a more apparent 'growth' of the earth's crust—an increase of its thickness in the course of the deposition of volcanic material and fragments resulting from its disintegration.

In the mobile zones the character of volcanic eruptions changes. At the beginning of the formation of the geosynclinal trough along the deepest fissures in sea basins-and-troughs we have the development of lavas and tuffs of the basic composition of the type of ferromagnesial basalts from the material of the magmas entering from the earth's depths, from the mantle.

In the subsequent stage, after the elevation of the ridge of the islands volcanic rocks of the medial composition were deposited—andesites and tuffs—and lastly, after the drainage of sea basins, foldings, the uplift of mountain structures, and at times their washout—this included the terrestrial volcanites with the deposition of thick masses of lavas and tuffs already of the acid composition as well as quartz-

porphyries. These zones of Cretaceous age extend over thousands of kilometres along the Asian margin of the Pacific belt, with the ones that are younger and belong to the Tertiary period stretching along the American periphery of the same zone. The latest basaltic outflows are correlated with the fissures that dissect the earth's crust.

The volcanic activity involving the proximation of the continent and the ocean continues even now. This is where we find the Pacific volcanic belt with 526 volcanoes, out of which 328 are active, while in the waters of the Pacific Ocean those are more than one thousand submerged volcanic mountains. The flat, even tops of some of them reveal that some time in the past the volcanoes rose above the sea level.

In the Pacific volcanic zones very large acting volcanoes of Kamchatka are situated: Klyuchevski, Bezymyani, Tolbachik, Karymski, Shiveluch and others; Alaid and Tyatya are on the Kuril Islands; in Japan we can see the world-famous beautiful Fujiyama.

There are numerous volcanoes in the Zunda archipelago, in New Guinea, and New Zealand. We can find a large number of volcanoes in the Pacific region of North, Central and particularly South America, where the volcanic cones crown the highest ridge of the Andes.

Another belt of volcanic activity is the

Mediterranean one. This is where the famous volcanoes Etna in Sicily and Vesuvius near Naples are situated. In the Soviet Union this mobile belt of young folding and contemporary tectonic activity includes the highest volcanic structures of Elbrus (5642 metres) and Kazbek (5033 metres). In Turkey the Ararat mountain is as high as 5465 metres.

The belt of active volcanism extends from Iceland along the Mid-oceanic elevation of the Atlantic Ocean.

Lastly, a very special type is represented by the African volcanic belt which emerged in the ancient crystalline continent along the most recent meridian deep faults that have fractured it. Among the 40 volcanoes there Kilimanjaro is the one that is best known (5895 m).

The volcanoes ('windows' into the depths of the Earth) help us to imagine the deep-seated structure of our planet and the processes that have been taking place since the earliest periods of its development. The study of volcanoes is also significant for practical purposes—their activity is connected with a large number of very important deposits.

The eruptions of volcanoes have attracted the attention of researchers since time immemorial. A description of the catastrophic eruption of Vesuvius during which the city of Pompeii was buried and the Roman

scientist Pliny the Elder was killed (79 A.D.) was rendered by his nephew Pliny the Younger.

I can still see the ruins of this buried city where after the excavations it became possible to walk as though it were a museum. But this is a sad museum indeed! We see the neat little courtyards and enter the houses where everything seems to have remained intact, even the frescos on the walls. The houses look as if they had not long been deserted. The other things 'on display' are the casts of those that perished. They were made by pouring gypsum into the cavities in the ash that remained at the place where the bodies were burnt. The positions in which we find the dead speak of their torments; the twisted body of a boy, what used to be a dog ... They were all killed when the city suddenly found itself under the hot sheet of ashes. Everything was destroyed by fire, after which mudflows covered every single part of the city.

The fatal end of Pompeii was depicted by K. Bryullov in his world-famous canvas. The pillars are coming down, people are in panic, but 'Now the patricians and slaves are all the same! It is too late to hope, and praying is in vain'.

A considerably greater eruption took place not long ago in Kamchatka, when in 1955 the Bezymyani volcano 'exploded'. Fortunately, however, there were no people

in the vicinity of the volcano. It was a relatively small hill, and in no way remarkable —an extinct volcano which was not even privileged to be called by any other name but Bezymyani, which in Russian means 'nameless'. I happened to be there in 1960, when it was possible only to hear the accounts of those who witnessed the eruption and saw its fantastic consequences.

At the time of the eruption the top of the volcanic cone was fractured and almost half of it was thrown out high into the sky, with its fragments showering upon the wide valley—the Klyuchevski valley later. The witnesses say that at first there was an explosion. Then they saw a black column of ash as high as 15 kilometres. The ash cloud spread over many kilometres right up to the volcanological scientific research station Klyuchi. Large particles (of the size of 3 millimetres), hammered on the window-panes as though they were a strong hail. The fallout of ashes was so great that inspissated darkness fell upon the locality.

The area covered by the ash reached 400 kilometres in length and was 100-150 kilometres wide. The general volume of the ejected material was not less than 500 million cubic metres. The thawing of snow which covered the top of the volcano resulted in the emergence of mudflows, which filled the wide valley with liquid mud and fragments of stone.

In several years' time at the place of the former flowering valley we saw an agglomeration of ash, volcanic boulders with black twisted trunks of burnt trees in the background.

What surprised us was a great thickness of the layer of volcanic deposits. The valley of the small river that flowed down from the volcano had been wholly buried under the volcanic material. But soon it made way for itself again in the loose sediments in that very same deep (30 metres) narrow canyon. This was where one could really feel the immense velocity of the processes of accumulation as well as the washout of sediments in the regions of active volcanism.

Very slowly we climbed up the steep slope of the volcano along the loose ash; and indeed the volcanic dust looked very much like the ash remains of a campfire. We were ankle-deep in them. Near the crater to the bottom of which one could rise as though it were a stage, the front wall was pulled down. There we saw smoke-like vapours. The volcano continued 'to breathe' and 'to smoke'. In the middle of the crater there rose a congealed lava obelisk. Its walls were continually breathing, and in the crevices it was possible to see a red lava melt at some distance. From the fissures there issued a new ash, which gave a silvery coating to the stones that only a day before were washed out by the rain. It was possible to de-

termine the amount of ash that fell out during the night.

As we were informed later, the lava andesite obelisk continued to grow (now it is already higher than 300 metres), and out of the fissures new though inconsiderable amounts of ash continued to be ejected. The volcano was becoming more calm, and with the squeezing out of the depths of the lava cone there took place a relief of tension of its deep-seated forces. In the first stage of the explosion 3 cubic kilometres of volcanic material were ejected from the volcano.

We certainly visited the famous Klyuchevskaya mountain—the one that reigns supreme over the rest of volcanism in Kamchatka. We did not risk climbing the high mountain—it is by no means a simple ascent! I remember one of the back issues of the 'Ogonyok' magazine (1938) with the colour photograph of a young woman and the legend saying that the first woman, Sonya Naboko, reached the peak of the Klyuchevski volcano. Today she supervises the work on the studies connected with the formation of minerals from the hot waters of volcanic origin. She has devoted all her life to the Kamchatka volcanoes.

There have been quite a few ascents to the Klyuchevski volcano since then. Though beautiful and peaceful from afar it is nevertheless trecherously dangerous. Some of the ascents resulted in the deaths of courageous

volcanologists. What was most hazardous to them was the rockfall, or a torrent of stones. This was the result of the fact that the snow on top of the volcano thawed a little, and the stones, deprived of any support, tumbled down at the ever-increasing rate along the slope. Sometimes the volcano erupted. Such eruptions were mainly connected with the radial fissure of the Yubileinyi rush. We can see there even now a number of small volcanic cones bearing the names of Karpinsky, Zavaritsky and some others of my acquainted scientists.

We stepped upon those unstable, rough ledges of black congealed basaltic lava. The liquid lava had flowed very rapidly here (400 metres an hour). It rolled over and over like the caterpillar of a tractor. At the time of one of the eruptions of the Klyuchevski volcano our courageous volcanologist Popkov together with his friends went down the lava stream, took measurements of temperature of the lava (which was up to 1050°) and selected samples of gases. It was undoubtedly a hazardous descent: the thin hot crust of the lava stream could have been broken quite easily. But this time all went well. The brave researcher perished during the World War II.

In the North of the Minor Kuril ridge we climbed up to Ebeko with a group of participants of a volcanological symposium. At the top of the volcano there lies in its depres-

sion a wonderful lake and quite close to it on the slope we can see the smoking solfataras, the white sulphuric jets that come out of the bowels. Above each of such jets there is a tall cone of native bright-yellow sulphur. We were all anxious to peep into the volcanic 'spring' which ejected a stream of sulphuric gases and to collect from the walls of the tunnel of this cone as many of the beautiful sparkling specimens of crystalline sulphur as we could. We tatted in the mountain and fell behind the other members of the excursion.

It was getting darker with every minute. We walked along the path from where we could see the brightly lit city of Severo-Kurilsk, which was rebuilt after the devastating wave of tsunami. Night descended upon us very soon. We lost the sight of the path, which could not be discerned even by our experienced guide. From the small mountain passes which we reached with no little difficulty there extended a clinging cedar creeper; the lights of Severo-Kurilsk were visible, and yet from the valleys which we passed through the ice-covered streams we could see nothing. We didn't know where to go?

Someone had timidly suggested that we should spend the night on the slope of the mountain and wait till morning. But we didn't even have the matches to light a campfire, while all around us there lay the last

year's snow that had not yet thawed. We were going in the direction of the star that we decided to have as our celestial landmark. Late at night soaked while crossing the little river, and chilled to the marrow we managed to reach our destination. They were all panick-stricken there and had even sent a rescue team which could not have found us since it went along the road while we chose the 'short cut'.

I had to pay heavily for my interest in solfataras. My tonsils burnt by the sulphuric vapours had been aching for quite some time.

It was very interesting to watch the eruption of the Tyatya volcano on the Kunashir Island in the south of the Great Kuril ridge. The beginning of the eruption coincided with our arrival at the island. It was only on the eve of that day that we admired this most beautiful volcano in the rays of the setting sun. Its perfectly structured cone seemed to have been truncated at the top by some horizontal line, and from this 'section', the caldera (sink) in its centre, there rose a small young cone. It looked as though there stood before us a giant, a broad-shouldered Circassian wearing a felt cloak. Fog was everywhere that night, and only in the morning we managed to get to the shore in our duralumin boat so as to get in touch with the local authorities. While we were speaking of our problems,

the telephone rang to inform us that the eruption of the Tyatya volcano had started.

On board the 'Geofizik' we took the volcanologist E. Markhinin and his group of assistants who were also in Kunashir, and made our way towards the volcano. At the entrance to it we got into an inspissated darkness, while ash was falling down like snow. We went round the headland so as to land near the volcano. The fallout of ash continued. Above the volcano we saw a tall dark pillar of ash, which was spreading upwards like an umbrella or a branched pine-tree. E. Markhinin asked the captain to determine the angle of inclination, the deck of the boat and the upper part of the ash pillar. It was found to be 8 kilometres! Our duralumin boat hit the shore near some settlement the population of which had been evacuated.

What we saw before our eyes was sad and strange. Everything was covered with ash. Its layer was 12-centimetre thick, thus burying the earth and even the fences. It was a winter landscape indeed, though instead of snow there was the grey ash that was shrouding the dejected bushes and the thick branches of the trees that were now heavily burned. The ones that still inhabited that place were the deserted domestic animals. Cows were actually crying with tears. Their udders were heavy and we had

to milk them, and then to give water to the horses, pigs and cattle.

As we found out later, bears had run away from the volcano. Swimming birds got together and took wing, and clouds of birds eclipsed the sun.

E. Markhinin and his assistants went in the direction of the volcano, while we came back to our boat and continued to work along the shore, collecting bottom samples of the sand. Only at the appointed time we came to talk with the volcanologists over the radio. From the vent funnel there rose a black cloud, which was now issuing a much darker ash than what it previously was. Zigzags of blinding flashes illuminated the nocturnal contours of the ferocious mountain. We were all anxious to hear something about Markhinin. No news came within the following twenty-four hours. At last we heard over the radio the words: 'He came back very tired and is now sleeping!' With enormous difficulties the volcanologists made their way along the eastern slope of the volcano. They went in the direction whence a black column of ash was rising. Later Markhinin used to tell us of the birds they had found lying dead on the ground—the unfortunate creatures that did not manage to fly away.

According to E. Markhinin's account of the eruption there had first been an explosion on the southern slope. This gave rise

to the formation of two explosion vents which the volcanologists called the maars of Vlodavets and Radkevich. They were situated along the 300-metre long fissure known as the Pluto's chain. The maars ejected stones of up to 20 tonnes which had completely devastated the age-long forest. At some distance away small stones peeled off the bark of the trees from the side that faced the bursts. Stones as big as bookcase were thrown out together with the volcanic bombs and incandescent ash material. What testifies to the high temperature of these ejections is the burnt trunks of the trees and the ash in the funnels that was still hot at the time when Markhinin was there. After the maars were formed on the eastern slope of the volcano there was a great explosion with the result that two craters originated—Otvazhni (courageous) and Pogranichnik (the frontier guard). Some time later the 300 thousand cubic metres of slag gave rise to the formation of two volcanic cones.

Leaving the Markhinin's group in the care of the Kunashir authorities, we went away from the volcano, circumvented the island and went back along the Minor Kuril ridge. At the distance of more than 200 kilometres from the place of the eruption the grass and the stones were covered with a layer of black ash.

The overall weight of the material erupted by the volcano was estimated by

E. Markhinin at 200 million tonnes, while the area over which the ash propagated was assumed to have been equal to 20 thousand square kilometres. This eruption took place after a certain period of rest: for nearly one hundred and fifty years the Tyatya volcano had slumbered and was considered to be an extinct volcano. However after the eruption in 1973 it has continued to show signs of activity.

There exist many descriptions of the volcano eruptions. The most prominent one in the history of volcanology was the explosion of the Krakatoa volcano in the Zunda archipelago. This event was duly discussed by I. Rezanov in his book *The Great Catastrophies in the History of the Earth* who took into account a great deal of literary materials.

The volcanic structure of the Krakatoa mountain was pulled down at the very beginning of the eruption, the crater was crushed. The explosions were accompanied by an underground humming noise. Columns of ash reached the height of 30 kilometres and it started to rain 'ash'. During the subsequent explosions gases, vapours, ash, and fragments of rocks were raised to the height of 70-80 kilometres! They were scattered over the area of 1 000 000 sq km. Huge waves of up to 30 metres high fell upon the shores of Java, washing away everything that was on their way.

Another horrendous event was the eruption of the Pelée volcano on the Island of Martinique. The incandescent cloud, which had afterwards become black, was wrapped in host of flashes, and rushed down the volcano, turning all into ash. It is now considered that the white-hot cloud contained a mixture of hot gases and scorching lava dust. The velocity was as high as 500 kilometres an hour. After this eruption the volcanologists have singled out a very special type of fiery clouds. Apparently, it is with these clouds that the formation of 'baked' tuffs is connected. The latter were widely spread among the subterranean volcanic rocks of the Far East.

These eruptions took place within the historical period. Catastrophies of much greater scope must have occurred in the past. One of them (the fourteenth century B.C.) is associated with the perishing of what was described by Plato as the legendary Atlantis. According to I. Rezanov this could have occurred as a result of the eruption of the Santorin volcano.

Into the sediments of the seas volcanoes bring huge masses of material. The amount of the ejected volcanic products of 12 eruptions from the year 1800 until now has comprised, as E. Markhinin estimated, 259.85 cubic kilometres! Mention is not made here of the washout of volcanic rocks of ancient eruptions; they too deliver a vast quantity

of the material into the marine sediments. But it is not only the solid volcanic products that enter the seas. On the same Kuril Islands the geologists have established that the stream running down the slope of the volcano, where the sulphuric volcanic gases come out, carries out in a dissolved state such substances as silicon, aluminium, potassium, sodium, as well as mercury, lead, and zinc. These elements enter the sea. The silica that is released from the volcano provides the basis for the algae of diatoms that absorbs silica. The accumulation of the remains of diatoms enriches the earth's crust with silica.

Part IV
The Composition of the Earth's Crust

The outer shell of the earth's crust is made up of rocks of different origin. They are sedimentary, igneous, and metamorphic.

Chapter 10
Sedimentary Rocks

Sedimentary rocks are formed mainly from the sediments in the water bodies. The origin of sedimentary rocks was not immediately conceptualized. For instance, as far back as the fifteenth century the Italians thought that the limestones with sea shells found in the mountains were formed at the time of the Biblical Flood. Such erroneous views were found to be untenable by the great scientist and artist Leonardo da Vinci. He was convinced that at the place of the then mountains there had once been a sea. After its recession the layers with sea shells were uplifted and could thus be found in the highest mountains. The same ideas were further developed by M. Lomonosov in his book *On the Layers of the Earth.*

Among the sedimentary rocks the frag-

mental variety is singled out. It is formed from the fragments of silicate rocks. The organogenic rocks, also belonging to the sedimentary group, emerged as a result of the activity of organisms. What is also distinguished here is the chemical rocks, the origin of which is associated with the sedimentation of various salts from sea and lacustrine waters.

The fragmentary rocks are preponderant among the sedimentary variety. They are the ones that are of secondary formation and emerged at the expense of the redeposition of the fragments washed down from the land, or the products of disintegration of other, more ancient rocks. In the water basins and within the continuously developing troughs they sometimes build masses that are 10 and more kilometres thick. We can get some idea about the origin of fragmentary rocks by observing the deposits of sediments in the present-day water bodies, and, mainly on the seashore.

I have always been keenly interested in this problem. In my travels along the shores of the seas in the Far East, or while motorboating in the littoral zones during the studies in marine geology I always watch the formation of sediments. What lends itself to observation and certain features pertinent to the sorting of the material according to its specific weight and size, which results in the formation of homogeneous layers. On

the beaches we can see that upon the thin layers of gravel and small pebble-beds there lie sands on top of which we see silts and then gravel again.

The very same alternation of layers can also be found in the outcropped rocks in the geological sections of the past. Very often it is a change in the innumerable interlayers of sandstone and clayey schist in the thick masses of sedimentary rocks. As is actually the case, nowadays these ancient layers are situated not horizontally as they were initially deposited in the sea basin, but are inclined since they have been crumpled into folds. In some hilly precipices, where masses of sedimentary rocks can be found, we can also see the forms of these folds that are either complex or simple and look like a piece of corrugated material or the sloping waves. It all depends on how much the process of folding effected the sedimentary masses.

Among the sedimentary rocks we find the conglomerates of pebble-beds and granular sandstones that were formed from the sand, as well as fine-grained clayey schists which originated in the silt. Each type of rocks reflects the conditions of sedimentation, e.g. pebble-beds are deposited near the very shore, the deposition of sands takes place further, and silts, which give rise to clayey schists at some later period, are settled far away from the shore.

A complex group is represented by the marine sediments formed from the salts that were dissolved in sea water. They can emerge directly through chemical sedimentation from the water in those places where the concentration of salts reaches a certain limit of saturation, as is, for instance, the case near the exits of mineralized waters of volcanic origin or during the evaporation of water in semi-enclosed bays and lakes that are separated from the sea. This was how there appeared first and foremost a large number of limestone beds—the rocks that are widely spread in the sedimentary shell. They can also be found in the mountain regions of geosynclinal and folded structures and in the plains whereupon the vast continental seas had once been spread. The age of limestones is different, ranging from the Precambrian period to nowadays.

The ancient organic concentrations of limestones are connected with 'structures' of stromatolites—the products of the vital activity of blue-green algae, that covered the floor of the ancient seas beginning with the Proterozoic age.

Limestones emerge in relatively warm waters and at a small depth, where life finds its most intense expression. They are dissolved when submerged to greater depths. However, when the optimal depth level is preserved and the fragmental material 'polluting' the sediments is absent, there

appear thick calcareous horizons. Conditions of this kind used to exist in the midland seas as well as upon elevations that were remote from the shores.

But in the littoral zones of the past we can see a frequent alternation of the layers of limestones and fragmental rocks. The character of geological section and the change of rocks itself helps to reconstruct the specific features of tectonic regime, the depth and temperature conditions of the seas in the past history of the Earth.

The evidence of the organic origin of limestones can easily be found since the remains of fossilized organisms are often discovered in limestones themselves. Sometimes it becomes possible to see real 'cemeteries' of compressed shells, or the so-called coquinas. This kind of mass accumulation of the remains of perished mollusks can serve as a proof of a certain catastrophe, or perhaps of a strong storm wave that threw them out onto the seashore. It could also have been a drainage of the sea bay, when the animals did not manage to swim away into the sea, and lastly the chemism of waters in the basin could also have accounted for the situation we can witness today. But in the ordinary conditions of the sea there also takes place a large accumulation of lime at the expense of the remains of perished animals. In the main this material consists of the shells of mollusks, though in

some places vast amounts of limestones are erected by the activity of the coral-polyps, which surround themselves with calcareous shells.

A particularly great rockforming significance is attributed to the structures of colonial corals, which give rise to structures extending over hundreds and thousands of kilometres—the barrier reefs or annular islands, the atolls, that surround the shoals or shallow-water lagoons.

The coral reefs are characteristic of tropical countries. The polyps creating them dwell in warm waters. The region of their propagation is a band, restricted by the latitudes of not more than 30° on either side of the equator. At the same time the growth of corals requires small depths of water, those that do not exceed 40-60 metres. Their surface habitation was brought to light by Charles Darwin during his voyage. The fossil corals can serve as indicators of depths and temperatures of the basins, in which they lived. The temperature pertinent to the formation of fossil cords is not specified by the relationship of oxygen isotopes within their calcareous shell.

The fact that corals are correlated with the surface region of sea waters can serve as explanation of the growth of their structures: the corals built their 'houses' upwards. Thus there emerge calcareous masses the height of which measures hundreds of me-

tres. The height of some of the coral 'trunks' reaches up to 10 and more metres, which may already be regarded as a genuine 'coral forest'. However, with the water level remaining constant, the polyps, while budding ramify horizontally, often forming interwoven 'branches'. You can readily imagine how exceptionally beautiful the coral structures are, if your friends had ever brought you a branch of corals from some tropical country in the south seas.

It is common knowledge that in the complex branched tubular calcareous separations their dwellers, the little polyps, inhabit only a very small upper part, or the terminal points of the 'branches'. The polyp dwelling is very small, sometimes measuring several millimetres in cross section, though built on top of the coral branches, it can require labour of many preceding generations. The polyp is an active builder. It surrounds itself on its own with a protective carbonaceous shell, and absorbs the lime that is dissolved in sea water. The myriads of those little builders, known as the infinitesimal polyps, have produced the most beautiful and enormous structures.

What is particularly famous is the Great Barrier Reef of Eastern Australia. It extends over one thousand kilometres and is parallel to the shore, and yet departs from it into those places where the water is clean and transparent and which is not polluted

by the sands and silts evacuated by the rivers. Flying over the eastern coast, we can see a little white band in the crystal-clear water. This is unmistakably a reef. And if you are lucky enough to take part in an excursion to the reef (the tourists often have this opportunity), you will be fascinated by the panorama of the subaqueous world. In the blue of the waters you will see a kind of enchanted stone forest with tall snow-white branches of 'trees and bushes', whose interwoven tubular 'branches' create the most whimsical patterns of stone lace.

The reef abounds in various inhabitants. What draws them here is the enormous amount of food, particularly the diversity of very small organisms, such as the plankton. You are bound to see how among the branches of corals there swim little groups of fish, while against the background of the bottom we cannot but notice the bright orange starfish and the black sea urchins, bristling with their long spines and numerous shells. In due time all these tenants will also make their contribution to the reef structures. Their shells and skeletons will become an additional source of lime for the formation of limestone.

Over the past ten years there emerged starfish on the Great Barrier Reef in Australia that destroy the coral structures. At present to save the unique coral reserve a war has been waged against the starfish.

But can we see the same kind of exceptional beauty of the reefs in the rocks of the past? No—time erases them. It is with no little difficulty that the geologists distinguish the traits of reef structures. They become destroyed in the course of the recrystallization of limestones and the plastic deformation under the pressure of overlying masses. And if our remote progenies or the inhabitants of other planets decide to study the limestones of the present-day Great Barrier Reef, in tens of millions of years, they will see nothing but compact greyish rocks not bearing even a trace of those miraculous structures created by such little builders as the colonial corals. However, sometimes the building of reefs, especially if the tectonic and hydrodynamic conditions remain unaltered, is procrastinated for tens of millions of years. This can be exemplified by the calcareous massifs of reef origin in Primorye, in which we can find the remains of fauna belonging to the time between the Middle Carboniferous period and the Lower Permian age, while in other places —within the interval covering the Middle and Upper Triassic.

The coral structures are destroyed while still in the sea and not only by the starfish and fish, but also by the waves. I can easily bring back to mind even now the blinding white beach in the south of Vietnam with the sand formed from corals. It contains

many beautiful branches and large fragments brought from the low coral island that shines white not far from the shore.

But the carbonaceous rocks can also be of other origin. Some of them were deposited chemically in the evaporating water basins.This is especially characteristic of Precambrian dolomites (carbonates of calcium and magnesium). The limestones are also formed from the fragments of washed out carbonaceous rocks, or are of fragmental origin. It becomes very important to determine the origin of carbonaceous rocks and the form of their massifs since they often contain large deposits of mineral resources (lead, zinc, strontium, etc.).

The same kind of variability can be applied to the origin of siliceous sedimentary rocks, which enter into the composition of thick beds, particularly in the deep troughs of geosyncline regions. The siliceous rocks can have a volcanogenic and sedimentary origin, emerging at the expense of the silica, that comes into the sea during volcanic eruptions. These types can be found near the former volcanoes. Silicons of this kind are closely connected with jaspers—the remarkably beautiful rocks of various colour—ranging from black and dark-red to green, grey, blue. The alternation of strips and irregular spots of different colour creates a wonderful pattern of a stone which now looks like the sea and mountains, and now

gives the impression of the forest and flowers. These are the so-called landscape jaspers, which are widely spread in the South Urals, and Altai, and have for long served as as the material for the handmade articles of jewellery.

Silica is concentrated by means of chemical sedimentation from sea waters as well as with the help of living organisms. It is absorbed by the infinitesimal diatoms — the algae that are very beautiful and whose form is extremely intricate. They are all diverse, in addition to which their form helps to determine the age of layers. Falling down upon the floor they form silts that are rich in silica.

Silica is also absorbed by the simplest unicellular organisms, the radiolarians — the tiny creatures that inhabit great depths. When perishing, they too give rise to silts enriched with silica. At the expense of these silts there later emerge layers of silicons or siliceous schists, that are not infrequently found in the sedimentary masses of geosyncline regions. The radiolarians, which are highly varied in form, also help to accurately establish the relative age of rocks. It should be added here that silica is concentrated by sponges too.

We have already discussed the questions concerning the emergence of sedimentary layers that were deposited from water upon the bottom of the water bodies or on land

in eolian sands and terrestrial volcanic layers of ash. Initially they were loose sands, soft clays, silts or fine-grained cinereous accumulations. But in the later period the sediments become more compact, there takes place recrystallization, new minerals appear in them, and what we usually find on the surface is already hard-stone rocks.

It is only in exceptional circumstances that there where the layers were deposited upon the hard ancient foundation and did not undergo any deformation at all, as is the case with the ancient stable crystalline shields, the sediments preserve their plastic quality (we may as well recall the Cambrian blue clays in the vicinity of Leningrad which were mentioned at the outset of the present narration). Now, in the areas of young volcanism, where hot mineralized waters make their way from the deeper regions into the surface, it is quite the opposite. Even the absolutely 'young' sands are sometimes turned into hard stones.

I happened to witness this extremely rare case on the Kunashir island in the South Kuril volcanic ridge. On the beach there were sand grains cemented by minerals that were deposited from the hot mineralized waters springing from under the earth. The sand was so hard that we could take samples of it only with the help of the geological hammer. Now, how surprised we all were when in this 'sandstone' we discovered

something that would equally surprise any of my readers. It was a bottle which proved that the hard rock was not more than five years old!

The fate of sediments is different indeed!

But, as a rule, sediments change over a long period of time. Under the pressure of the overlying masses they become dehydrated, the water that saturated them is gone, and what remains is a compact undissolved remnant, which in due time becomes even more dense and particularly in the deeper regions and transformed into a hard stone rock: the sand becomes sandstone; the clay takes the form of clayey schist; and the calcareous silt or the accumulation of shells transforms into limestone. They are the ones we see on the surface where these rocks are uplifted by the deep-seated forces of the Earth.

Chapter 11
Magmatic (Igneous) Rocks

Magmatic rocks emerge from the melts erupted to the surface during volcanism or rocks that are solidified at a certain depth. Thus, the term 'igneous rocks' which is sometimes used to designate them does not fully reflect their origin. The same group includes not only the rocks that have been erupted by the volcanoes, but also those

that have been crystallized from the magma in the depths of the Earth.

The composition and origin of rocks is the domain of petrography, the science which originated in the second half of the nineteenth century, when polarizing microscope was discovered. This instrument helps to precisely determine the minerals by regarding the optical properties in the thin and transparent plates of the rock, or the sections, which was found to be useful in establishing their interrelationships and the complex processes that were taking place at the time the rock was formed.

Over the past decades the processes pertinent to the crystallization of igneous rocks from silicate melts are studied experimentally: what is melted includes either rocks or the mixtures of chemical compounds, corresponding to their composition. This is followed by a close study of the successive crystallization of minerals during the congelation of melt in different conditions.

However, the main source of our knowledge about rocks and their origin is still the geological observations and primarily those that concern the current processes of the formation of rocks from lavas. As far back as the beginning of our era the inhabitants of Italy, the witnesses of the eruption of Vesuvius, knew that the erupted fiery melt is transformed into hard stone during the process of congelation. But this knowl-

edge was not transferred to other countries, and even at the end of the eighteenth century the famous German scientist A. Werner regarded granites and basalts as sedimentary rocks. The proponents of this trend were called neptunists. The opposite views were held by Scottish geologist James Hutton, who asserted that granite was an igneous rock. In honour of Pluto, the god ruling over the lower world, his followers received the name of plutonists.

To the refutation of the erroneous ideas of neptunists a certain contribution was made by Russian scholars. At the end of the eighteenth century V. Severgin tried to prove that basalt was an igneous rock, while at the beginning of the nineteenth century the one who struggled most actively against the concepts advanced by the neptunists was the professor of St. Petersburg mining corps D. Sokolov.

According to the place of formation magmatic rocks are divided into volcanic (effusive) and plutonic (intrusive). The former are developed in the course of the solidification of the products of volcanic eruptions (lavas, ash) on the surface, while the origin of the latter is associated with the crystallization of magma in the deeper regions.

In accordance with their composition the rocks of either of these two groups are classified depending on the percentage of the

main rock-forming component — silica (SiO_2) into ultrabasic (35-40%), basic (40-52%), intermediate (52-65%), and acid (60-70% and more) varieties.

The higher the content of silica is, the more acid and bright the rock seems to be. The ultrabasic rocks very poor in silica acid have the colour ranging from dark green to almost black ones. They consist of silicates of iron and magnesium —olivine, pyroxene and the oxygene compounds of iron and titanium. This can be exemplified by peridotite, pyroxenite, and dunite. On the surface they are widespread in a small quantity but they consist of deep-seated shell (the mantle) of the Earth.

The substance of which the mantle consists generates into the Earth's horizons along the deep faults in the form of melts of ultrabasic magma or in hard pinched plates. After erosion the ultrabasic rocks become exposed on the Earth's surface. The melts that have flown out upon the surface give rise to ultrabasic volcanic rocks, or komatites.

The ultrabasic rocks are connected with various mineral resources —platinoids (platinum, osmium, iridium and other metals of the platinum group), nickel, copper, and chromium. The alkaline varieties of ultrabasic rocks, or kimberlites that pierce through from the greater depths in diatremes, may well be associated with dia-

monds. When ultrabasic rocks undergo changes there emerge the deposits of asbestos.

The basic rocks are often connected with the ultrabasic ones. They are the light, relatively acid 'melts' from the ultrabasic mantle. In the upper part of the earth's crust they are spread more profusely than the ultrabasic variety.

A typical representative of plutonic basic rock is gabbro. It is a granular dark-grey rock which consists of pyroxenes, amphiboles and calcosodic feldspars that are rich in calcium.

The basic group also includes the feldspathic deep-seated rocks or anorthosites, which consist mainly of labrador, or plagioclase substantially enriched with calcium. These rocks are found in the ancient masses of the Earth and have recently been discovered on the Moon. Another better known labradoritic rock is labradorite — which is famous for its exceptional beauty: little crystals of titanic iron ore, the ilmenite ($FeTiO_3$), included into plagioclase sparkle and reflect the light from the faces of crystals. This produces an inimitable play of colour (iridescence) with a variety of diverse shades of blue. The dark funeral labrador is largely employed as tombtone. We can see it on the facade of the Lenin Masoleum.

In the mobile belts of the earth's crust

the plutonic basic rocks, just as the ultrabasic ones, emerge in the early stages of the development of geosynclines from the melts of the deep-seated pallial origin.

The principal effusive basic rock—the volcanic analog of gabbro—the compact, dark basalt is widely spread throughout the Earth's surface. It is assumed that it enters into the composition of the lower part of the earth's crust. It was precisely with the basaltic outflows that the formation of the Earth's sialic cover had begun.

Basaltic lavas outflowed in all geological epochs: in geosynclines in the early stages of their development as well as on the platforms, thus giving rise to vast plateau of the so-called traps. Basalts are the main rocks of the ocean bed and island arcs; in the latter they are found together with andesites—the volcanic rocks of median composition.

Basic rocks are characterized by their own complexes of ore elements: iron, vanadium, copper, and titanium. This type is correlated with large titanic deposits of the Urals. The destruction of the massifs of basic rocks may well be associated with the placers of titanic minerals—the ancient paleozoic variety as well as the contemporary ones, including those on the ocean shelf and in the marginal seas.

As is the case with the ultrabasic variety the intrusive basic rocks often form massifs

along the deep faults. Sometimes they are accompanied by rocks of the average composition, which are also the product of the basic magma.

The intermediate rocks represent a transition to the acid ones. They are richer in silica and consequently have fewer ferromagnesial dark-coloured silicates and feldspars having more light colour. Besides calcosodic plagioclases there also emerge potassic feldspars: orthoclases, microcline and even small quantities of quartz. What exemplifies plutonic rocks of average composition is diorite as well as granodiorite, while volcanic rocks are illustrated by andesite and dacite.

Diorite is a dark-grey granular rock, consisting of feldspar and dark-coloured minerals (hornblende, pyroxenes and biotite). This stone is very attractive, especially when polished. The Leningradians can readily imagine what diorite looks like by associating this stone with the figures of the Atlantis supporting the entrance portico of the Hermitage. Those who will visit Leningrad must come to know these remarkable works of sculpture, and learn something about geology at the same time. It is worth mentioning here that diorite enjoyed particular favour with the ancient sculptors of Egypt in their work on pyramids and the busts of pharaohs.

Granodiorite is even a more acid and light

rock, which is transitory as regards the granites. In addition to plagioclase it already contains a vast amount of potassic feldspar (more than in diorite), and quartz —the mineral that manifests a high degree of silicic acidity contained in a rock.

The effusive analog of diorite is andesite. It is a greenish grey compact rock which is characteristic of Neogene Pacific volcanic islands, where their propagation serves as the indication of 'andesitic margin'. It is also developed among the Neogene volcanites of the Mediterranean zone.

Dacite is a rock that is even more acid and light in colour. It is an effusive analog of granodiorite.

It is with the intermediate rocks that the ore deposits of gold and silver, copper and molybdenum, lead and zinc, as well as other metals are connected.

The acid rocks that are the richest in silica include granites and the volcanic varieties that are closely related to them, e.g. quartz porphyrs, liparites and other acid effusive rocks.

We all know about granite from our school textbooks. The information we find there says that it is a granular igneous rock, consisting of feldspar, quartz, and mica. The combination of variegated minerals renders granites a 'mottled' colour: the granitic pebbles resemble the spotted pigeon eggs. We can actually speak of the de-

tails in the composition of granites: micas, for instance, can be black (biotite) or of light silvery colour (muscovite). Besides mica, we can also find hornblende. Feldspars can also be different as far as their composition is concerned. The combination of relatively acid plagioclase that is poor in silica and potassic feldspar (orthoclase) may be considered to be quite usual. However, there also exists plagioclase (plagiogranites).

Ages ago granites were used for construction purposes and the building of monuments. In Ancient Egypt the monoliths of Aswan granite that were sent down the Nile, were used in erecting monumental columns —obelisks. One of them is now in Paris in Place de la Concorde where it was brought to by order of Napoleon. The second one is in London, and the third is in New York. One of the columns (the column of Alexander the Great) can even now be seen in the temple of the ancient Egyptian city of Luksor.

The granites were employed by the Egyptians in making figures of sphinxes, which were procured by the Russian emperors and today serve as ornaments on the embankments of the Neva River in Leningrad.

It must also be mentioned that the embankments of the Neva are faced with a specifically red granite known as rapakivi. I often visit Leningrad and never stop admiring the peculiar structure of the rock

with its spheroidal feldspathic and quartz removals of the same minerals in a fine-grained mass. Granite is widely used in the facing of the metro (the underground) and the walls of public buildings. This gives all those who love stones an ample opportunity to acquaint themselves with this kind of rock.

We can see granites practically everywhere. The processes of granitization played a substantial role in the formation of the earth's crust and today the greater part of the ancient crystalline shields is composed of granites, which account for the fact that the upper part of the earth's crust has received the name of the Earth's granitic layer. The average composition of the Earth, however, is closer to granodiorites than to granites proper.

Granites are widely propagated in the geosyncline-folded belts, where their land masses emerged during the period of folding and the general elevation of structures, and sometimes after folding had taken place.

The forms of granitic masses are of different kind. Within the folded belts this often finds its expression in elongated large massifs along the zones of fractures. Massifs can go down to markedly great depths (batholiths) or have the form of plates, sometimes of interlayered variety, formed during the spreading of magma between the layers of sedimentary rocks. This is accompanied by

the emergence of mushroom-like bodies called laccoliths.

The stage following the process of folding is characterized by the development of the so-called minor intrusions—the veins (dikes) and stocks, or the columnar compact bodies with small cross section and which emerged at the intersection of fissures.

The origin of granites can be various. They can emerge, for instance, from the crystallization of the magma that enters from the deeper regions, and which can be formed during the melting of the sediments and ancient crystalline alumosilicate rocks. They can appear during the replacement of rocks by the aggregate of minerals that are typical of granites but that have been separated from the hot solutions.

The granites are closely associated with the ore deposits of tin and tungsten, as well as rare metals, such as beryllium, lithium, tantalum, and niobium.

A diversified complex of minerals is often connected with pegmatites—the macrocrystalline varieties of granites. Pegmatites are highly specific rocks which, as is the case with granites, consist mainly of potassic feldspar, quartz and mica, but are markedly coarse-crystalline, distinguished by a peculiar structure. The principal minerals—quartz and potassic feldspar, which are separated at the same time in parallel and regularly oriented growths, are character-

ized by complicated and whimsical sinuous borders and give rise to a peculiar pattern, which looks like the Hebrew letters: pegmatites are called graphic granites, or the Jewish stone.

Pegmatites are found in the form of veins and tubular, plasstic, pocket-like bodies, that often have a zonal structure: the margins are fringed by coarse crystalline mica, then comes the main zone of the growths of quartz and potassic feldspar, with the 'quartz nucleus' in the middle. They are distinguished by large and one might say even gigantic dimensions of crystals. Thus, in one of the feldspatic crystals of Ural pegmatites enough space was found even for an adit! Huge crystals of the size of logs are formed by lithium pyroxene (spodumene). The plates of mica can also be of enormous size. It was precisely the pegmatites that in the past provided the material for the window-panes of the people of Muscovy—the fact which may well account for the name of 'muscovite' that this light mica had received.

Pegmatites are deep-seated formations. They were developed in different periods of the Earth's history, but were particularly characteristic of the ancient epochs of the Precambrian period, the time when the largest deposits of rare metals of Africa, South America, North America, and India were formed (tantalum, niobium, tin, and be-

ryllium). We can also find pegmatites in the folded belts of the Paleozoic age. In the Urals, in the famous Murzin quarries Izumrud (emerald) mines, and Ilmen preserve, where for a very long time precious stones for the Russian Empire were recovered. Pegmatites are also known in the zones of Mesozoic age (the Transbaikal), though they are but secure in the Cenozoic folded belts.

A classic study of pegmatites belongs to Academician A.Fersman, who regarded these formations as a result of crystallization and prolonged transformation of granitic melts enriched with the volatile compounds of fluorine, boron, and chlorine. Academician A. Zavaritsky put forward a hypothesis pertaining to the formation of pegmatites through the replacement of alumosilicate rocks by feldspar, quartz and mica under the influence upon them of high temperature aqueous solutions, saturated with volatile and rare elements.

It becomes apparent, as in a large number of other cases, that the truth here lies somewhere in-between. The pegmatitic bodies with regular ingrowths of quartz and feldspar emerged from fluid, which, according to its physical state, represented something intermediate between the melt proper and a mobile concentrated liquid solution saturated with gases. After the solidification of the 'framework' of feldspar, quartz and mica, the later portions of residual gaseous

solutions changed pegmatite and caused the replacement of the earlier formed minerals by the new ones. In the place of potassic feldspar there developed the sodic variety (albite). The same can be said of topaz (the mineral of fluorine), lithia mica. This also involved the deposition of various ore minerals. The significance of these processes of replacement in the transformation of pegmatites was particularly stressed by A. Fersman himself.

Among the igneous rocks a special subclass is formed by alkaline rocks. Their representatives can be found among the ultrabasic and basic types as well as the granitoidal series. These rocks are correlated with deep faults of the activized platform structures. They are accompanied by large concentrations of phosphorus, rare earth, and rare metals. The deposits of Khibin apatites connected with alkaline rocks are well known.

What helps to purposefully conduct the quests of the deposits is the establishing of the regular associations between the mineral resources and particular types of rocks.

We can directly observe the formation of rocks from the melts during the volcanic eruptions and then by analogy imagine the processes of the crystallization of magma in the deeper regions too, though the effusive and intrusive varieties of rocks are markedly different, the former are massive,

often vitreous (obsidians), while the latter are coarse-grained, which are crystallized slowly at a gradual drop in temperatures.

However, there is much in common between these two varieties of rocks. Both of them are characterized by the 'quenching' zones of the cryptocrystalline rock (vitreous in volcanites), formed during their rapid congelation in the peripheral parts of the magmatic bodies. The degree of crystallization increases as the distance from the contacts becomes greater. The transitions and interrelationships between effusive and intrusive rocks can be more propitiously observed in volcanic complexes.

The formation of volcanic rocks during the cooling of lavas lends itself to observation in the contemporary volcanoes of the Kuril Islands and Kamchatka. Processes of the same kind also took place in the past, when enormous volcanic belts were coming into existence.

And how then can we imagine the formation of deep-seated rocks? How can we become convinced that the neptunists of the end of the eighteenth century were wrong, when they considered that such rocks as granites and basalts were sedimentary as clays and sandstones, and that the plutonists were right? Nowadays, the views held by the plutonists concerning the origin of igneous rocks from magma may well be considered to be irrefutable.

Try to imagine that together with our small geological team you are also studying the volcanic belt of Sikhote-Alin which extends along the shore of the Sea of Japan and the Tatar Strait for more than two thousand kilometres. The masses of volcanic rocks—quartz porphyrs and tuffs—have the thickness here over two kilometres, while the width of the belt measures up to more than 150 kilometres. This is where from the depths of the Earth huge masses of volcanic material have been erupted (over 200 thousand cubic kilometres!) This enormously great volume of volcanic masses had been formed for as long as 50 million years. In the Late Cretaceous and Early Triassic periods, when the volcanic activity was characterized by systematic resurgence, streams of lavas flowed out along the fissures; they were mainly of the acid composition, and high into the sky big clouds of incandescent ash were ejected from the volcanic necks. It was carried away by the wind, and stuck together in baked laminated masses that then became hard tuffs.

But why, when speaking of the deep-seated intrusive rocks, we have again returned to the volcanic varieties? The fact is that within this belt, besides effusive quartz porphyrs, we can also find intrusive granites. The formation of these types of rocks alternated in time, and in some places they are connected with gradual tran-

sitions: in the deeper regions of those vent tunnels there appeared crystalline rocks similar to intrusive varieties too.

Thus, join our excursion along the littoral volcano-plutonic belt of Sikhote-Alin.

In a small boat we are moving near the slope. When I say 'we' I mean myself, the mechanic, and two students from Moscow. We are now approaching the high vertical hills composed of whitish quartz porphyrs and tuffs. The rocks lie almost horizontally; in places the masses of volcanites are slightly wavy. From time to time our little boat brings us to the shore where we take the samples. We shall study them under the microscope, and then let the laboratory people have their chemical and spectral analyses. One of our friends is wrapping the stones very neatly together with the labels, and does all this aboard our little boat.

But this is where we have to stop! What marked change of rocks: vertically the light quartz porphyrs have been replaced by grey rocks. They are already granites. We are at the contact of the granitic massif, which we must examine very carefully. This is followed by an itinerary on foot along the shore. We are making our way through the disintegrated blocks piled up on mountain slopes. In some places we get down into the water and trudge on the slippery wet stones, without taking our shoes off.

The contact is really interesting. It is steep, and we can see that the granites are breaking through the volcanic mass. The massif is branched off: the veins are of the same granites, though of the fine-grained variety. And in the massif itself, at the contact, the rock becomes fine-grained, and then in the narrow zone it is found to be wholly compact, cryptocrystalline, and looks very much like the effusive rock. This is the zone of quenching at the contact with the cold volcanites. Quartz-porphyry changes also near the contact. They get more compact and harder at the expense of silicification, and darker due to the little scales of black-mica—the biotite. This means that we have clearly established that granites break the masses of volcanic rocks.

On what depth then has the unfortunate magma which did not manage to find the exit onto the surface been solidified here? We know that its congealation had taken place under the screen of steep volcanic masses, presumably at an inconsiderable depth: suffice it to say that the thickness of the roof here does not exceed 2 kilometres (the maximum thickness of overlapping volcanites). The magma intruded between the layers of volcanites, thus forming in them what may be called quaquaversal bulges. In this place granite is very closely related to quartz-porphyry, being their intrusive associate. My colleague is dauntless-

ly climbing up the vertical hill supporting himself on the bushes, and trying to find the tiniest fissures wherein he can put his foot for at least a little while. I watch his hill climbing with apprehension. I remember how several years before Yevgeniya V. Bykovskaya of the Leningrad Geological Institute in the same kind of ascent along a vertical hill that was more than one hundred metres high instead of a branch got hold of ... a snake! The reptile did not hesitate to sting the offender's hand.

My son Radii was in the same team with Yevgeniya Bykovskaya. He worked then as a collector. They made a joint effort to get to the top of the hill. Radii sucked the snake poison from the wound, and in several hours' time they came to the hospital. Her shoulder was swollen, but in the long run all went well. The geological map of the volcanic belt compiled by Bykovskaya has faithfully been serving those concerned with surveying and prospecting. Her observations provide valuable material to those who study volcanic complexes.

But . . . we have digressed from our itinerary. Now we are on the shore going along the granitic massif. In light granites we can see rounded dark spots—the inclusions of gabbro and diorites. Hence, other rocks had been formed in the depth even prior to granites. They were fractured and their pieces were captured by the ascending

granitic magma. Now they are xenoliths—the inclusions of alien rocks. It is possible to imagine that the inclusion of magma was also spread in time and was characterized by several events: the crystallization of early dark basic and intermediate rocks and later acid grey granites of the principal phase. However, neither the grey granites had completed the history of the formation of intrusive complex.

A little further on the grey granites are intersected by the veins of red varieties: these are already the new portions of magma, which has entered from the same source. Apparently it was more acid and enriched with potassium (the rock receives its red colour from the abundant orthoclase).

If we continue our journey, we shall certainly come across the youngest light granites. They are also known in this region, but we saw them later, away from the shore in the Sudno mountain.

The Sudno is an unusual mountain that can be seen from afar with its flat top which is exactly what makes it look like a ship (in Russian the word 'sudno' means 'a vessel'). The flat form of the top is conditioned by the cover of young lava. In the main the mountain is composed of Cretaceous granites (the age of which is 100 million years), that become exposed within the steep creek valley in the interval of 400 metres. Granites intersect the Upper Cretaceous volcanic

rocks, but are themselves overlapped by a horizontal layer of Early Tertiary lavas.

It is interesting to observe that within the range of the massif it is also possible to see the transitions from the coarse-grained granite at the bottom of the slope to the porphyraceous variety in the upper part of the outcrop. Presumably, the granitic massif became crystallized at an inconsiderable depth and in the process of decrystallization in the upper part of the body, near the roof, approached the typical volcanic rocks. Then the thick blanketing of the ancient volcanites of the massif roof was washed out by the surface agents (weathering, and the activity of all-devastating waters). The granites were exposed, intersected by erosion, and already after a long period of time the Tertiary lavas of the new magmatic Tertiary cycle at the age of about 50 million years were deposited upon their washed out surface. Such was the long (50 million years) and complicated development of the belt of volcanic and intrusive rocks which we, following the remarkable Soviet geologist E. Ustiev, refer to the volcanoplutonic type.

Complexes of this kind were first observed by E. Ustiev in the Cretaceous volcanic littoral zone of the North-East of the Magadan region, we find the analog of these complexes in Primorye. I remember how at the time of our expedition with him he pointed

out their development in the Tertiary volcanic belts of the Carpathians too, and laid particular stress on their significance in the formation of more ancient Paleozoic volcanic belts (for instance, in Kazakhstan). Thus, we can trace a close bond between the effusive and intrusive formations in the volcano-plutonic belts through the whole history of the Earth.

Now we are studying the volcano-plutonic complexes of Sikhote-Alin in Primorye, which is highly important not only for theoretical, but also for practical purposes: rocks of this complex are connected with the deposits of tin and tungsten, lead and zinc, gold and silver. In other words, what we have here is a case when the scientific interests are inseparable from those of practical importance. It is essential that we should become convinced in the direct cognate association of effusive and intrusive rocks, in order that we could pass on to more comprehensive conclusions about their origin, the development of magmatic processes in terms of time and the prognostication of ore content.

And so, let us return to our itinerary along the coastal rocky outcroppings of quartz-porphyry of the littoral zone of the Sea of Japan. This is where all the interrelationships of rocks can be clearly seen in the vertical section.

The materials of our excursion clearly

show the cognate bonds between the intrusive and effusive rocks. In its turn this helps us to unquestionably transfer the observations of the contemporary lavas to the magmatic processes of the past, right down to the deep-seated intrusive ones.

At the same time our region reveals a successive evolution of the melts from the basic (gabbro) to the intermediate (diorites and granodiorites) and up to acid (granites) varieties. This makes it possible to approach the discussion of more general problems of the evolution of magmas.

Thus, magma is a lava that has been solidified at the depth. We can imagine it as a boiling mass with glacing lights of orange and crimson. It is impregnated with volatile water vapours and various gases, bubbling and spilling over, as it were, all the time. From this fiery source gases are emitted along the fissures, while the melt itself is divided in the deep-seated chamber into parts of different composition. The light components, such as slag, go up, and the heavier ones come down. Sometimes the earlier crystallized ferro magnesial silicates are subsided. After their separation what remains is already a more acid melt. In this and some other ways there takes place the differentiation of magma in the deep-seated chambers. We find here a change in the composition of the absorbed enclosing rocks. Their assimilation results in the emergence

of the so-called hybrid rocks, which further complicate the pattern pertinent to the development of intrusive process.

However, in large massifs granites are often found to be homogeneous. A great volume of granitic bodies and volcanic acid masses of volcano-plutonic associations enables us to assume that the source of acid magmas is mainly the sialic acid crust, which is remelted under the influence of the deep-seated basic magma, solutions and heat flows, that came from the Earth's mantle.

And where then is the origin of all the impulses of magmatic activity? At this place of our narrative we are obliged to go back to the discussion of those questions which have already been touched upon at the beginning of the book, and which concern the deep-seated structure of the Earth and the evolution of the Earth's matter. We cannot possibly treat this very difficult problem without coming back to some of the previously discussed items now and again.

If our knowledge about how the rocks are formed from the melts is more or less authentic, though not precise (we might as well recall the various processes pertaining to the formation of granites), we can say that we know but very little about the origin of magmas themselves, or rather practically nothing, and are thus obliged to confine ourselves to almost plausible hypotheses that are not incompatible with geophysical data.

We already know that the melted sources under the volcanoes are situated at different depths—from 200 kilometres and less. These sources move upward, the fact which is registered by the geophysicists, who predict the time of the expected eruptions.

It is considered that magmas enter from the asthenospheric layer—the region of the mantle at the depths of 100-200 kilometres, where, judging by the decreased velocity of the propagation of seismic waves, minor function is performed by the liquid phase of the deep-seated substance. It is in this region that the initial division of the magma according to composition begins. What enters the asthenosphere is the relatively light basaltic melts from the ultrabasic hard substratum of the mantle that float upwards. Their protrusions give rise to the so-called asthenoliths, projecting in the upper direction in the form of torch-like tongues. Penetrating during the undulate movement of the lithosphere still higher along the faults, the basic basaltic magma reaches the earth's crust.

Here in the different stages of the development of mobile zones the process acquires various trends: the large faults or the gaping faults of the initial early parts of the growth of geosynclines make the geosynclinal troughs accessible for the basic magma. When there appear gaping faults in the continental blocks, the mantle (?) can presum-

ably be partly exposed itself too, or its hard plates can be squeezed out. In this stage there prevail the basic magmas that flow out onto the surface (basalts) or fill the deep faults (crystalline gabbroids and ultrabasalts).

It is not the same with the processes that take place in the late stages of the development of geosyncline mobile zones. The overall elevation of the folded structures coincides with the movement to the top of already acid magmas, which results in the formation of massifs of granites. Acid magmas emerge during the melting of the earth's crust in the course of the intrusion of deep-seated pallial melts under the influence of the rise in temperatures. This new melt has very much in common with the granodiorites, which correspond to the average composition of the outer sphere of the earth's crust. The extensively comprehensive propagation of rocks of the granitic group (granites, granodiorites) on their continents and their lack in the oceans enables us to regard them as intracrustal formations. In these cases when different types of magma (the initial ones and those that have been formed anew) are blended, there appear hybrid melts of average composition.

The processes relevant to the evolution of melts also continue in the overlying magmatic reservoirs (in the intermediate sources on their way upwards), as well as at the

place of the solidification of magmas; this is where we can find the further progress of the subsidence of the heavy ferromagnesial part of them (the ferromagnesial silicates) and the floating of light residual melts towards the upper region and the pinching of the late remains that have been enriched with silica and volatile compounds in the concluding stages of the crystallization of magma and that give rise to acid granites of the later period.

This was the course of events that we had established at the time of our student itinerary.

Still later there appear small intrusions of basic rocks (dikes of diabases, basalts) at the expense of that heavy sediment in the magmatic chamber, with the formation of which the differentiation of magma within the deep-seated basin began. In our region these dikes are closely interwoven with ore veins. They proceed along exactly the same fissures, intersecting the main part of ore veins, and, in their turn, are intersected by the ore veinlets of the latest association of minerals of stanniferrous deposits.

Chapter 12
Metamorphic Rocks

The metamorphic (transformed) rocks compose a great part of the earth's crust, mainly its deeper regions as well as the mantle.

The change (metamorphism) takes place in those parts of the rocks, where conditions become different as compared with those that existed at the time of their formation: temperature and pressure rise, and various solutions or gases that penetrate through the pores exert their impact upon the rocks. All rocks whether they are sedimentary, igneous or metamorphic, are subjected to metamorphism.

Under metamorphism the changes in the rocks more often take place by means of the recrystallization of minerals in a hard state excluding any process of melting, and more seldom, as a result of either partial or in the deeper regions of a complete melting of rocks.

Why does metamorphism occur?

The rocks while subsiding to the depth in the process of folding or their subsidence along the faults find themselves under circumstances that are quite different from those in which they originated, i.e. within the region of high temperatures and pressures, at which the minerals entering into their composition become unstable. For instance, limestone, formed in the past on the surface of the Earth, occurring in conditions that are not typical of its emergence (at the contact with hot intrusive massifs or at the depth where the masses subside in the course of tectonic movements), undergoes recrystallization. Its basic composition

does not change. What is removed from it during recrystallization is only the admixture of carbonaceous substance, and the compact grey limestone becomes responsible for the origin of snow-white crystalline marble, sparkling with the faces of its crystals.

More complicated transformations take place in the sandstone consisting of various minerals. The following sequences may prove to be helpful in tracing the development of one mineral from another: the grains of plagioclase—mica (muscovite), orthoclase—kaolin, dark-coloured silicates (hornblende, pyroxene), as well as fragments of basic rocks—ferromagnesial chlorites. These newly-formed minerals inherit the chemical elements of host minerals in place of which they appear (isochemical metamorphism); what is added in the early stage of metamorphism is only water which enters into the composition of newly-formed minerals. The latter most often have a foliated or platy form, and their crystals are oriented parallel to the slackened planes at a right angle in the direction of the pressure acting vertically in the deeper regions.

Thus, there emerge schists characteristic of the early stages of metamorphism, which finds its expression at the moderate depths, there, where the rocks are saturated with waters that penetrate through them. These heated waters are precisely the main agent of metamorphism. The clayey masses give

rise to silvery micaceous schists (phyllites), and the basic lavas and tuffs have the same effect upon the green chloritic schists. This type of metamorphism is referred to the facies of green schists, while the process of chloritization of basic volcanites is called a greenstone change.

The development of schistosity, the parallel-laminated structure, is characteristic of the majority of metamorphic rocks, is brought about by the oriented arrangement of minerals, particularly of the laminated type of micas flattened across the directions of the pressure.

This process of flattening of a substance under the activity of pressure can be exemplified by a cube of plasticine upon which we exert the pressure of our finger. The cube is thus flattened and transforms into a plate. The same happens to minerals in the case of metamorphism, with the only difference that instead of spreading, as is the case with plasticine, we find here its recrystallization; at some of its parts (from where the pressure acts) the crystals are dissolved, at the others (where the growth of crystals is not hampered by anything) the crystals continue to grow and increase in size. This is how the spreading out, as it were, of mineral formations takes place, which are then extended into parallel bands. Particularly distinct is the schistosity in those rocks that contain tabular water-bearing minerals,

e.g. micas and chlorites, the scales of which form a parallel pattern.

From what has been said it follows that rocks can change to a different extent, depending on the depth and the tectonic conditions where the processes of their transformations took place. Three zones of various depth with a different degree of the change of rocks under regional metamorphism are singled out. They are: the upper zone called the epizone, the middle zone, known as mesozone, and the lower zone, which is referred to as the katazone. The deeper the rocks subside into the depth the more progressive the degree of their metamorphism becomes. This is called progressive metamorphism.

The metamorphic formations of the upper epizone of the metamorphous 'column' were discussed in the earlier parts of this book. They are basically the schists with the water-bearing minerals, such as micas and chlorites, or facies of green schists.

Under more considerable change of circumstances, an increase in temperature or pressure, or both these factors (mesozone), there appear other types of minerals: there takes place the development of hornblendes (amphiboles), as well as feldspars and other anhydrous silicates. When the temperature and pressure increase, the water is removed from the minerals of these rocks.

This is known as the amphibolic facies of metamorphism.

Still greater subsidences (katazone) are correlated with the recrystallization of minerals. Under the influence of pressure minerals become arranged linearly, along the planes of schistosity, in addition to which there emerge crystalline schists, gneisses and other types of markedly transformed rocks.

The deep-metamorphosed granular rocks of katazone with no features of schistosity are referred to the granular facies (stage). Granulite is a granular rock formed from orthoclase and quartz with the admixture of other minerals, which has originated at a considerable depth and that is characteristic of the early Precambrian metamorphic complexes. When the pressures are high we can find at the depth or within the tectonically active zones the formation of an excessively compact rocks, or eclogite, consisting of garnet, pyroxene and quartz (the eclogitic facies). It is assumed that eclogite is also developed in the upper mantle.

The emergence of garnet in the deep-metamorphosed rocks can be explained by a very close 'packing' of the atoms of this mineral. It is also supposed that in the deeper regions and under high pressure there also appears a variety of silica that is denser than quartz and that is now known to us as stishovite.

Thus, we can establish the dependence of the composition and structure of metamorphic rocks on the conditions of temperature and pressure, i.e. mainly on the depth, where the processes of metamorphism were taking place. It goes without saying that what has an important influence on metamorphic rocks is the original rock.

A special type is represented by the so-called ultrametamorphism, when all the initial features of the original rock are wholly destroyed, and there takes place its melting or the replacement by new mineral aggregates. Thus, during the melting of clayey schists, sandstones as well as ancient granites and gneisses granites emerge.

An almost complete transformation of rocks is also achieved by the high-temperature mineral solutions, which deliver from the depths new complexes of elements, such as potassium, silicon, volatile compounds of fluorine and chlorine, which, acting upon the rocks, cause a deposition in it of new minerals. In addition to this granites also appear. Examples of this kind of granitization can be found near the intrusive granitic bodies, where veinlets of feldspar and quartz that give rise to granular aggregates, and sometimes to large feldspathic crystals developed within a mass of sedimentary rocks can be seen. When changes of this kind have a marked form of expression there appear pegmatites—the banded rocks the composi-

tion of which is similar to granites, and which are formed at the place of laminated sedimentary rocks and which have retained their structure in the linear orientation of minerals.

The processes of ultrametamorphism are particularly characteristic of markedly changed ancient complexes, though such formations can also be found in the younger ones. During a gradual subsidence of the masses into the depths of the Earth various types of metamorphism can find their expression in them. Sometimes, however, metamorphism recurs at the time of the new outbursts of tectonic activity (polymetamorphism).

In some cases there takes place a change of already metamorphosed rocks during their elevation from the zone of deep metamorphism. This is where the composition of minerals changes too. In the upper zone, saturated with water, that penetrates through the pores of a rock, hydrous minerals emerge. They are the same kind of micas and chlorites that develop from the deeply metamorphosed gneisses. This is an expression of regressive metamorphism.

What is copiously exemplified in the deeper zone includes processes of granitization, in addition to which granites are more often formed in the case of deep metamorphism (and melting) of clay rocks. As a result of a continuous transformation of

earth masses there emerged the gneissose granitic outer shell of the earth's crust.

We have just been discussing the processes of the general, or the so-called regional metamorphism over the vast territories as a consequence of the overall subsidence and the rise in pressure under the load of the overlying masses.

No minor significance should also be attributed to local metamorphism, which can be defined as the transformation of rocks when in contact with the melted masses (contact metamorphism), or in the tectonic zones of crumpling (dynamometamorphism).

Contact metamorphism becomes particularly apparent near granitic masses. Vapours and gases, as well as streams of gaseous-water solutions, emitted from the cooling melt of magma, penetrate into roof of the massif along the pores and fissures in the rocks, at times bringing about their complete transformation.

Sandstones and clay rocks give rise to hornfels—hard compact rocks, consisting mainly of quartz, mica, feldspar, sometimes with garnet, sillimanite (Al_2SiO_5) and other minerals of the same group (kyanite, andalusite).

At the place of limestones in contact with granites during their recrystallization under the impact of high temperature the so-called skarns emerge. They are compact rocks consisting of garnet and pyroxene.

The composition of skarns is already quite different from limestones from which they have developed. These contact rocks appeared at the expense of the supply of silica, magnesium oxides, iron, manganese, and only calcium oxide (and sometimes also magnesium) was developed on the spot from carbonaceous rocks.

In a large number of cases skarns appear already after the solidification of granitic massif in tectonic fissures at the place of its contact. This is where we find complicated chemical interactions at the contacts of rocks of different composition, the elements of which react between themselves under the influence of hot gaseous-water marginal solutions that enter from the deeper parts of magmatic massif. The solutions bring various metals which are deposited in the fissures, replacing (ousting) the skarn-forming silicates: pyroxenes, garnets and others.

This type of iron is known for its large deposits. Such are the magnetite deposits in the skarns of the Urals (the Blagodat and Magnitnaya mountains), in Western Siberia and other ore regions. The magnetitic ores in skarns are an important source of recovery in the USSR and other countries. Of no less significance are the skarn deposits of copper and tungsten (Tyrnyauz in the Caucasus), lead and zinc (the Dalnegorsk group in Primorye).

This is the role of contact metamorphism, in which case there takes place a complete replacement of rocks and their enrichment with ore elements that come together with the solutions from magmatic bodies. What we have here is no longer an isochemical process with the preservation of the general chemical composition of rock during the regrouping of its elements; it is the case characterized by the addition of many elements (including those of the ore varieties) from the magma and the replacement of a rock by a mineral substance of different composition. The process when the former minerals are wholly replaced by the new ones, different in chemical composition, is called metasomatosis. However, metasomatic processes sometimes occur alongside the metamorphic ones proper and against their backgroud, for which reason skarns too are referred to the group of contact-metamorphic formations.

Thermal changes can also become apparent in connection with volcanic processes, when the masses of young sediments (tuffs) are saturated with hot mineralized solutions, which deposit new compounds (mainly those of silica). We may as well recall the geiserites in Kamchatka, of which mention has already been made. But exactly the same hot waters penetrate through the masses of rocks to still deeper horizons, thus promoting their transformation.

Besides thermal metamorphism there also exists its dynamic variety—the change of rocks under a marked oriented pressure. These changes are particularly characteristic of lengthy and narrow tectonic zones, along which solutions from the deeper regions are circulating. Typical dynamometamorphic rocks are the so-called blue schists, in which alkaline hornblende (glaucophane) receives no minor development. In the ore regions they are the thermodynamometamorphic rocks in the narrow zones of crumpling with the development of micaceous and chloritic rocks, enclosing the lenses of sulphide ores, rich in copper (Ural), with lead and zinc (Altai).

There exists a notion that the older the rock is, the more metamorphosed it becomes. Very often it is exactly the case. A large group of metamorphic rocks is typical of the Precambrian period. It includes charnockites, gneisses, and granites with a special type of orthorhombic pyroxene (hypersthene). What is particularly typical of ancient Archean complexes is grey plagiogneisses. They are widely spread in the Kola Peninsula, where they enter into the composition of vast territories and, as has been shown by deep boring and geophysical research, go down below. Granular granulites, or rocks from feldspar and quartz, are found to be characteristic of the ancient masses. Some horizons of monotypical meta-

morphic rocks are spread over a great area, which helps to compare various geological sections.

In the course of time the types of processes pertinent to metamorphism must have undergone certain changes. It is assumed that in the early Archean period there existed specific conditions of metamorphism in the then young earth's crust.

V. Shuldiger, who is known for his research into the metamorphic masses of the Far East in the Precambrian period, has a suggestion that in the early stage of the development of the Earth the physical conditions in the upper layers of the earth's crust and on the surface were different from what they were later. The earth's crust developed in conditions of high temperatures on the surface under the impact of hot atmosphere of the type of what is known on Venus today. The activity of acid gases, entering during mass volcanic eruptions, served to encourage a rapid change of the initial earth's crust, of which no trace has reached us at all. The earliest metamorphic rocks of the protocrust have not been preserved since they were destroyed under the superimposition of subsequent processes.

Specific conditions of the deep change of rocks had existed over the Archean and early Proterozoic periods, when gneissose granitic domes and green-stone troughs encompassing them were being formed.

The most intense metamorphism with the supply of a large number of elements from the deeper regions took place within the area of elevation, and in the gneissose granitic domes, which were basically formed in the process of granitization. Domes of this kind also emerged in the later period—in the Phanerozoic age, though their massive growth refers to the Archean period, when the granitometamorphic layer of the earth's crust was mainly formed. At that time there also took place the melting of the earth's crust in the zone of ultrametamorphism with the inclusion of the magmatic massifs of granites and the formation of copious pegmatites with the richest rare-metallic mineralization.

Thus, if not qualitatively, then in terms of quantity the early Precambrian period was distinct from the subsequent epochs by an intense development of the metamorphism of the earth's crust.

It is noteworthy that in the greenstone Archean belts metamorphism is sometimes expressed but poorly. For instance, the volcanic rocks of the greenstone belts of the Canadian shield are outwardly (and the degree of metamorphism) correlated with the neogenic volcanites of the Kuril Island arc. Hence, the degree of metamorphism is by far not always the criterion of the age and depth, as it depends largely on the tectonic conditions. There also exist dia-

metrically opposite examples of a high degree of metamorphism of the rocks in Kamchatka. According to the extent of their variability some of them have much in common in the Archean ones. The geologists have been arguing for a long time on the subject as to what age the metamorphic masses of the Median Kamchatka ridge should be referred to: the Precambrian or Mesozoic period. Presumably either of the two types can be found there.

'It occurs that in the tectonically active zone of the Pacific Ocean even the young Cretaceous masses have largely undergone the process of metamorphism, which can be compared with deep facies. This kind of metamorphism finds its particularly intense expression in the zones of deep faults.

Within the tectonically active Pacific region even such rocks as eclogites, which had previously been considered to be superdeep formations, typical of the mantle, can actually be found, as was established by the Soviet scientist, A. Marakushev, among Phanerozoic complexes.

Thus, the degree of metamorphism depends not only on the depth of its manifestation (and age of rocks), but also on the tectonic conditions and on the presence of the zones of permeability, in which the influence of pallial solutions and gases has different forms of expression. And yet it is the regular change of rocks connected

with the depth and the transition from the young to the ancient varieties that the main tendency of the process of metamorphism is most often found: the rise in the degree of their metamorphism from the epi- to the meso- and katazones of metamorphic column.

Hence, our question: 'Can the degree of metamorphism serve as the criterion for establishing the age of rocks?' may only tentatively be answered in the affirmative.

The scientists investigate the composition of metamorphic rocks and their minerals. According to the combination of minerals and the subtle peculiarities of their composition they can determine the thermodynamic conditions, which the rock found itself during various periods of its transformation. This is exactly what helps to reconstruct the history of geological processes and the geochemistry of the development of the substance entering into the earth's crust.

The scientific study of metamorphism is an important branch of geological sciences. It helps to understand the characteristic features pertinent to the processes that take place in different conditions, including those in the deeper regions, as well as to approach the question concerning the nature of the compact part of the earth's crust which is tentatively (and probably erroneously) called the basaltic layer by the geologists.

As has already been mentioned, instead of the assumed basalt the drilling of a super-deep borehole in the Kola Peninsula revealed that at the depth there were metamorphic rocks that resembled the basalts only in terms of density. The research into metamorphic rocks and their properties can thus be found also useful for the solution of general tectonic problems of the deep-seated structure of the earth's crust.

The study of metamorphic rocks is highly significant for practical purposes. Metamorphic rocks are connected with various mineral resources: the deposits that are formed in the process of metamorphism, such as those of mica, graphite, talc, aluminous rocks—aluminium ores, as well as precious stones (sapphire, ruby)—transparent coloured varieties of corundum (aluminium oxide). Contact skarn deposits include iron ores (the Blagodat and Magnitnaya mountains) and many non-ferrous metals (copper, lead, tungsten, and others).

In the overall community of rocks of the earth's crust metamorphic rocks are highly important members, particularly because it is precisely they that enter into the composition of its foundation, the greater part of the lithosphere, and possibly the Earth's mantle, too.

Part V
The Movements of the Earth's Crust

More than two-thirds of the Earth's surface is covered by oceans and seas, and only one-third of it is accounted for by land. The land is situated in the greater part of the North—the vast Eurasia and North America that was only recently connected with it. In the Southern Hemisphere we have the fragments of the ancient hypothetical continent Gondwana: South America, Africa, Australia and the Antarctic Continent, which occupy less than twenty per cent of the total area of continents. Some time ago there were scientists who thought that in the initial stages of the development of the Earth, when its volume was smaller, the continental crust embraced the whole Earth like an armour. During the subsequent expansion the integral shell was split and oceans, separating the 'fragments' were formed.

As has been pointed out earlier, the earth's crust on the continents is different from what is in the oceans. On the continents it is found to be thicker, particularly in the regions of high mountains whose 'roots' go deep down into the mantle, in

the same way as the large floating icebergs are more deeply submerged than the smaller ones. This is the law of equilibrium (isostasy). As distinct from continents the crust under the oceans is thin and is deprived of the 'granitic layer'.

In its turn, the structure of continents is not the same: two main types of structural elements, as far as the history of their development is concerned, are distinguished. They are the stable vast platforms and the mobile narrow zones—the geosynclines.

Platforms are level stretches of land known as plains. They are the calm, practically immobile blocks of the earth's crust: the whole wanton activity of the deep-seated geological processes is here something that now belongs to the remote past. However, there are instances when activization, or the recurrence of tectonic movements, takes place in them too.

Chapter 13
Mountains Old and Young

There where we have stable platforms today, tempestuous phenomena were raging some time before: magmas were moving up the fractures from their very depths, streams of lava were being erupted, and layers were being regularly folded. The elevation of high mountains was regularly succeeded by their de-

struction. All this continued for billions of years until the earth's crust here did not become so hard and uncrushable as a result of its melting by granites and other magmatic rocks, that it did not react to tectonic forces. It had already become a stable block!

But the ancient mountains did collapse. Time was merciless to them too; and the stone giants could not evade senility either. Over millions of years the destructive work was produced by streams of water, the wind, and marked changes in temperature before the mountain ridges were 'truncated' and in their place plains emerged. Then the former mountain region experienced only the smooth subsidences and minor uplifts. In cases of tectonic settlings it was invaded by the waters coming from the ocean or still existing the contiguous and mobile zones—the geosynclines, and there appeared shallow vast seas. They were characterized by the deposition of limestones (this is where the carbonaceous masses of the Moscow region are worth mentioning again) and the fragmental rocks (during the recurrent rewashing of the fragments of the formerly destroyed mountains). These new laminations gave rise to the emergence of the platform mantle, which is composed of horizontal layers and those rocks that are now altered but little.

The stable ancient hard blocks had been lying calmly, and the deposition of the

platform mantle overlying them remained undisturbed. But this was also to a certain period of time. There were cases when the tectonic movements along the faults were resumed, and then during the processes of the recurrence of movements (activization) the old mountains acquired what may be called the second youth. However, we shall speak of this later.

From under the mantle the most ancient historical masses on the platforms came out into the uplifted blocks, or shields. Studying the ancient rocks at these points of outcrop, the geologists get some idea about the processes that go back into the remote past, the great perturbations and 'revolutions', which had taken place here many times beginning with the earlier periods in the geological history of the Earth.

We saw an example of the destruction of old mountains in Araval mountain regions in the northwest of India. The hills scorched by the Sun most vividly reminded me of the foothills in the sultry Central Asia....

It was very interesting to hear the story of an Indian geologist that billions of years ago there were mountains as high as the present-day Himalayas at the place where we stood then. The Himalayas, however, had been elevated to the height of over eight thousand metres quite recently, in

the Tertiary period, just as the Pamir, contiguous to them from the north, or the mountain chains of the Tien Shan situated further.

I am well acquainted with the young mountains of Central Asia with that steep hilly slopes and deeply entrenched valleys along which rapid mountain rivers rush downwards. I often climbed these mountain in my childhood and afterwards when I became a geologist. What remained particularly indelible on my memory is the crossing of the south Tien Shan and the Pamirs during the expeditions of 1929-1930.

A narrow caravan path lay across the Alai ridge and took us into the wide Alai plain, from which we could see the further part of the Transalai ridge that stood in the south like a high wall. The ridge was crowned by the highest snow peaks with the Lenin peak among them. Our task consisted in discovering the routes to it so as to help the ascent of the mountain climbers, N. Krylov, E. Abalakov, and N. Gorbunov. Then came the pass across the Transalai ridge, where it was so high that it took one's breath away, the deep river valley of Muksu lay to the south, and behind it the majestic wall of Peter the Great ridge made itself visible again. The change of the relief was within the range of up to three thousand metres.

I happened to go up the rivers that were indicated on the maps only with hardly perceptible blue dotted lines. In their upper parts I was as fortunate as to discover glaciers. The greater part of the Pamirs had still remained a 'blank' then.

In the young mountains, that emerged at the place of mobile zones, the geosynclines, I had done quite a bit of work even later. I can very well remember the peaks of Vietnam with their steep precipitous slopes, where in the ravines the wanton vegetation of tropical jungle clutches the hills; the enormous ridges of North American Cordilleras and Rocky Mountains, and the highest Stanovoy ridge in the south of the Far East. How sharp the contrast is between these young ridges that rise as though they were steep steps over the flat platform plains and the old gently sloping mountains of the type of the Urals.

What were then the forces that uplifted these tremendous mountain structures and brought the deep-seated bowels of the Earth to the surface?

Factors underlying processes of this kind lie within the domain of theoretical tectonics. What also enters into its scope is the problems pertaining to the origin and deep-seated structure of the Earth.

Chapter 14
The Deformation of Rocks

Layers of sediments in the seas and oceans, rivers, as well as on land, sands, clays, silts, and pebble-beds, as you have seen yourselves on the beaches, shores and in the shallow parts of the rivers, lie horizontally or slope down a little. In the mountains, however, the beds of sedimentary rocks have either an inclined position, lie vertically, or as the geologists say 'stand on their heads'. These dislocations of the initial deposition of beds are the result of the gradual, though continuous, movements of the earth's crust, or the processes of folding.

And yet, it would not be out of place to mention here that what the geologists mean by 'folding' does not always adequately express the character of the deformation of rocks. It is seldom that we can see densely compressed folds that would remind us of what we get when ironing our clothes; in most cases what we see on the surface of the Earth looks more like waves, that are either gentle or steep, in which the stone beds have been crumpled. The concave parts of the folded series are called synclines, the convex ones are known as anticlines, whereas the transition between them is referred to as limbs.

The folded series of many anticlines and

synclines give rise to the so-called uplifted arches, the anticlinoria, or sinks, the zones of subsidence—the synclinoria. In the first case more ancient rocks come out onto the surface, in the second it is the youngest ones.

The folds are made more complicated by faults or fissures, along which the blocks of rocks are displaced vertically (faults), horizontally or 'aside' (shifts), or, lastly, during the thrusting of plates one on top of the other (overthrusts).

Great were the underground forces which could give corrugated shape to stone layers. All this is the work of indefatigable Pluto! Sometimes its activity increases, which might be due to the influence of cosmic factors (the cyclicity of the path covered by the Sun in the Galaxy is worth mentioning here). The periods when the movement of the earth's crust becomes enhanced are recorded by folding. This is determined by the unconformity of the rocks, when the underlying layers are crumpled in a different way and usually to a greater extent than the overlying ones that have deposited on its truncated and washed out surface.

The deformation of the earth's crust reached maximum value in the particular stages of the Earth's development. The number of such periods of folding was great in the Precambrian period (fifteen)

and in the period closer to our own (Phanerozoic) there were five of them.

The main stages of folding since the end of the Precambrian period have been the following: Baikal (in the late Precambrian and lower Paleozoic), Caledonian (in the lower Paleozoic), Variscian (in the Mid-Upper Paleozoic), Alpine (in Mesozoic and Cenozoic). The last of these, as the one that is less remote to us and better studied, is further more subtly divided into Cimmerian (Mesozoic), Laramian (on the boundary between Mesozoic and Cenozoic), and Alpine proper (Cenozoic). All these minute subdivisions of phases of young folding will come in handy in the further part of our disquisition.

The phases of folding can also be distinguished in more ancient stages, but we shall not complicate our easy discussion by delving into a more difficult classification.

We can hear the echoes of contemporary tectonic movements in the catastrophic earthquakes, particularly strong ones in the zones of young folding—in the Alpine belt (e.g. the devastating earthquake in Skoplje in Yugoslavia), as well as in the Pacific belt (the earthquake in Chile that has brought so much ruin). And yet, strange as it may seem, the territories of the more ancient folded regions as, for instance, those of Central Asia, do not remain quiet either. As a result of the activization of

tectonic movements and the uplift of large geological blocks along the faults there appeared such highest mountain structures as the Pamirs and Tien Shan as early as the Tertiary period. The movement in this region continues even now; it found its expression in the catastrophic earthquakes in Ashkhabad and Tashkent that we all know so well.

What then are the forces, that though gradually and continually, yet intensely in the long run, dislocate and deform the rock masses? The nature of these forces, as well as the form of folds and the types of faults, enter into the domain of tectonics. Tectonic studies are part and parcel of geology whose significance can hardly be underrated. With its help the geologists (in their mines) move continents, elevate the mountain structures and form deep sinks in the earth's crust.

Tectonics is studied not only by those scientists who are directly concerned with tectonics, but also by geologists as such in their everyday work on compiling geological maps, and in surveying and exploring the deposits of mineral resources.

We still remember the research we did in the Dalnegorsk ore region of Primorye. The question concerning the series in the lamination of masses and rocks had been puzzling us for quite some time. The difficulty consisted in that the limbs of faults

were inclined in one direction and it was not clear which beds were ancient and which of them were younger.

What presented particular interest was the position of the beds of limestone in a geological section. At the contacts (boundaries) of limestones with other rocks in this region the lead-and-zinc orebodies are deposited, and consequently it was very important to specify the form of limestones for the correct planning of exploratory operations. Everything seemed to be quite clear: the Permian silicons lay under the Triassic limestones, with Jurassic sandstones and schists above them.

But it so happened that new people arrived and began to study traces on chip planes made by the worms which at one time inhabited the sea. According to these traces it became possible to establish the genuine upper surface of the bed. We were thus obliged to form quite different ideas. The whole section was found to be overturned, as it were: the rocks which we considered to be ancient occurred to be the youngest.

However, this did not put an end to all the riddles of the Dalnegorsk sedimentary mass; they crop up before the geologists even now. What can be said about the nature of limestones? Are these layers uninterrupted or do they present discrete massifs of the type of reefs, which had been in the process of development for a long

time? Nowadays there is some proof that they were reefs! We are in quest of ores near them.

For practical purposes it is very important for the geologist to know the structure and primarily the folded structure in other regions too. It is particularly the case where the mineral resource is correlated with some specific bed or horizon. There the geologists very often elaborately plot on the map all the details of folds, which help, so to speak, develop a coal bed by taking into account all its complicated bends.

It is also important to know the form of folds during the exploration of ores. The author happened to see a bedded copper deposit in Japan, where the copper-bearing horizon was stripped in the limb of a syncline. The geologists plotted it on a map very carefully in the form of an oval.

Faults present no minor interest for investigation either. One can hardly do the exploration or recovery of a mineral resource without studying them. Imagine that a geologist is exploring some vein and is building an adit (tunnel) along it. Everything seems to be clear and simple: all one has to do is to move onwards in the direction of the vein, but the vein ... disappears, and is nowhere to be found.

There is a transverse fissure in the face, along which the continuation of the vein

is displaced. But where? The geologist is racking his brains. Much work and elaborate investigation in the face in the weak light of the miner's lamp will be required before the geologist will decide the route of the exploration so as to find the block that has been shifted, and the miners, watching him very closely, come up with their suggestions.

We have already mentioned minor tectonics, with which the geologists are concerned in their daily research of small territories, when they compile geological maps, survey and exploration of mineral resources. But these small tectonic forms manifest themselves against the background of the larger ones and in association with them.

For instance, in Primorye, where our Dalnegorsk region is situated, what influenced the formation of folds was the large faults, or shifts. Gigantic faults fringe the Pacific Ocean. They were of the first importance in the formation of the Pacific ore belt. This is where enormous shifts with horizontal dislocation were established. Thus, for instance, is the San Andreas shift in California; no minor one is in New Zealand. The same can be said of some other parts of the world. Contemporary movements with horizontal displacement along the shifts of this kind are substantiated by precise geodesical and space surveys.

Overthrusts with the dislocation of one mass upon another along the gently sloping and sometimes almost horizontal surfaces can be of enormous dimensions. They are particularly characteristic of the Mediterranean Alpine tectonic zone. I remember that at a coal deposit in the district of Moravská Ostrava in Czechoslovakia we were shown geological profiles and maps. According to the data of boring holes this is the place where ancient rocks are deposited upon the younger ones, i.e. we have here a case when the main principle of stratification that the superimposed (overlying) layer should be regarded as the younger one, is not substantiated.

During our excursion across the Rocky Mountains in Canada we saw a large number of horizontal or gently sloping scales, or plates, of Carbonaceous Paleozoic rocks thrust upon each other. When the scales (tectonic plates) undergo displacements of this kind the width of the band that was previously occupied by the beds of Paleozoic limestones was estimated by the Canadian geologists to have been reduced by 250 kilometres! Thus, the gigantic overthrusts are actually quite genuine forms of tectonic dislocations, though the scale of their displacements gives rise to incessant theoretical arguments.

The theory of the preponderant role of the most prominent overthrusts was at one

time widely spread in geology indeed. Attempts were made to make use of it in the thirties to interpret the structure of the eastern parts of the USSR, and the Transbaikal region in particular. However, it proved to be of no practical significance when applied to Siberia. On the other hand, in reference to those areas that have a different geological structure (the Alps, Carpathians, Rocky Mountains, and the Atlas Mountains in North Africa) the theory was found to be quite tenable.

Over the past few years and in connection with the development of a new hypothesis of the so-called global or plate tectonics many geologists have returned to the concept pertaining to the prominent function of overthrusts—the tectonic gently sloping plates in the make-up of the mountain-folded structures. This is something that will be discussed later.

Chapter 15
Fixism vs. Mobilism

What then were the factors conditioning the deformation of the earth's crust and how were the forces that brought about the formation of the folds, fractures of different kind and the dislocation of rock masses directed? The geologists are unanimous in their opinion that what lies behind all the deformations is the forces that are issued

from the deepest regions of the Earth. However, there exist different views on the actual source and the direction of the acting tectonic forces. Some geologists think that the main role in folding should be attributed to the horizontally directed forces, whence there emerge the compression of the layers into folds, and the overthrusts of scales with horizontal dislocation. The geologists who adhere to these views are called mobilists. The proponents of opposite opinion, the fixists see the principal sources of movement in the vertically directed forces, and reject any kind of prominent horizontal displacement.

The two sides have been arguing for years on end, considering themselves to be irrefutably unerring.

The geologists of the fixism trend (V. Beloussov and others) assume that the source of the main vertically directed tectonic impulses is the partially melted layer of the mantle, or the asthenosphere, which lies as deep as 100-250 kilometres from the Earth's surface. What rises from the asthenosphere is the light basaltic component parts in the form of melted gigantic drops of asthenoliths, which bring about the melting of the hard cover of the Earth, and also disturb the equilibrium in the earth's crust itself, thus causing the tectonic movements.

The elevations and subsidences of the

vast spaces of the Earth's surface, the uplift of mountain structures, the formation of folds and large faults, along which there takes place the elevation of magmatic masses and hot aqueous solutions from the depths are the result of the activity of the vertically directed forces. In the opinion of this group of researchers no considerable horizontal dislocations of the blocks of the earth's crust could ever have occurred.

The most distinguished representative of mobilism in his days was A. Wegener, who in 1915 published his hypothesis concerning the so-called wandering continents, floating, as it were, upon the deep-seated plastic shell. These ideas came to Wegener after he saw that the contours of the continents, primarily those of South America and Africa, coincided most markedly.

Wegener's very interesting theory captivated the minds of a large number of geologists in the twenties of the present century. According to this concept the southern continents, e.g. South America, Africa, Australia with Hindustan are parts of a huge fractured southern continent of Gondwana, and North America and Eurasia are also the separated parts of the northern supercontinent.

Try at your leisure to cut out the contours of Africa, South America, India, and Ma-

dagascar and put these 'cuttings' on top of each other. The fact that contours coincide will strike your eye indeed. The effect will be further enhanced if what we take into account is not only the contemporary littoral contours, but also the relatively narrow little band of shallow water, or the shelf.

Wegener's hypothesis drew attention on not only the scientists, but also on non-specialists in geology. The most attractive thing about it was that the shapes of continents are practically the same. This idea finds its cogent expression in the case of the Atlantic Ocean, the shores of which—the eastern (African) shore and the western (American) shore—illustrate a remarkable similarity of contours. That is exactly why it is assumed that they are the parts spreading along the faults of what was once an integral whole.

Some evidence has recently been produced that the geological structures upon these now disconnected continents were the continuation, as it were, of each other. This can be exemplified by the rare-metallic ore belts of West Africa and the eastern part of South America. What also coincides is the arrangement of the zones of ancient glaciation that seem to have been cut into parts by the newly-formed ocean.

There was a period when the attention to Wegener's ideas slackened, but over the

past few decades they were brought back to light in the hypothesis of plate tectonics. The proponents of this hypothesis, however, speak of the movement of not the continents, but larger lithospheric plates, which include even a part of the oceanic crust, and that are spread over a great depth (up to 200 and more kilometres) into the upper mantle, and that move along the underlying plastic and partly melted shell of the asthenosphere.

What are these ideas based on? They emerged after the oceanologists, within the period of the latest decades, discovered an enormous system of mid-oceanic ridges, which, girdling the Earth, pass through all the oceans, and mainly in their axial part. It was the greatest finding of the century in the wake of which many other theoretical conclusions and assumptions ensued. It occurred that in the axial part of these oceanic ridges there were fractures which gave rise to the outflow of deep-seated basaltic lavas upon the sea floor. Investigations have made it clear that the age of these lavas is the youngest in the axial part of the ridge and more ancient at some distance away from it. This is what brought forth the idea about the expansion of the ocean floor and the young age of the oceans themselves, the theory that substantiated Wegener's hypothesis.

One of the fundamental elements of

this theory is the concept pertaining to the widening of the ocean floor, or about the gaping faults in the mid-oceanic ridges. This expansion, however, has to be somewhere compensated for by compression. Otherwise, the general expansion of the earth's crust and the lithosphere would be quite apparent.

The authors of the theory of plate tectonics find some characteristics of a contrary process in the reduction of the surface of the earth's crust in the peripheral parts of the oceans, where, as they assume, there takes place the 'moving up' of oceanic crust under the continental one along the gently sloping zones, inclined in the direction of the continents. Zones of this kind do really exist! They have long been established by the volcanologists and seismologists according to the arrangement of the sources (hypocentres) of deep-seated earthquakes, which lie within the wide zone, dipped towards the continent. These hypocentres are situated at the depths of up to 700 kilometres. These are the zones above which the volcanoes are being developed.

Zones of this kind were discovered by the two scientists, Benioff and Zavaritsky, quite independently of each other, and have since been known under their joint names.

Those who adhere to the hypothesis of plate tectonics willingly make use of the

data concerning the zones inclined in the direction of the continent, and, as we have already mentioned, suggested that along them there takes place an underthrust, or the 'involvement' of the oceanic crust under the continental one, which is precisely reducing the overall surface of the ocean bed, thus compensating for its expansion when gaping faults occur in the mid-oceanic ridges.

Masses, drawn into those parts that underlie the continental crust, move in the deeper regions backwards in the direction of the mid-oceanic ridges, and thus there takes place a rotation of the substance of which the earth's crust consists, which is very much the same as the rotation of a caterpillar tractor. In accordance with the precept of plate tectonics there exist various types of the contiguity of plates. Plates move in the asthenosphere: (1) from the regions of expansion—the mid-oceanic rift ones—to the regions of compression at the periphery of oceans—towards the Benioff-Zavaritsky zones, that fall under the island arcs of Japan, Philippines, and Indonesia (the West-Pacific type), or (2) under the mountain-folded high structures of the continents (the Andean type). The third (Mediterranean-and-Himalayan) type represents the midland joints where the plates underthrust each other and there appear the highest folded struc-

tures. The rate at which the plates move is from 2-3 to 10-12 centimetres a year. In addition to the zones of compression and extension shift zones of transformed fractures are distinguished.

The hypothesis of plate tectonics has received a very wide, practically general, recognition in countries outside the USSR.

Besides the main plates that were initially singled out by the French researcher Le Pichoné (the Eurasian, American, Indian, Pacific, and African varieties), we can now speak of other plates too, including the minor ones, such as those represented by the Japanese, Philippine and other ones.

In the Soviet Union a major contribution to the development of the concept of plate tectonics was made by the oceanologists (A. Monin), the physicists (O. Sorokhtin), the tectonicists (P. Kropotkin and others).

O. Sorokhtin made an attempt to estimate in mathematical terms the most important processes that take place during the formation and development of the Earth, on the basis of geological, geochemical and geophysical data that were taken into consideration.

Where then does the factor conditioning the dislocation of plates and the tectonic movements of the Earth in general lie? The Soviet geophysicists and physicists (E. Artyushkov, O. Sorokhtin) see it in

the processes that take place in the deeper regions of the Earth. O. Sorokhtin considers the main source of excitation of the movement of the mantle to be the processes of interaction on the border of the outer nucleus and the lower mantle where, according to Sorokhtin as a result of the penetration from the mantle into the nucleus of new portions of iron (in the form of the Fe_2O protoxide) there is a growth of the nucleus and the change in the composition of the mantle as well as the enrichment with silica.

The convection streams that thus emerge capture the whole of the mantle. From them there diverge horizontal branches which break the lithosphere into plates and bring about their horizontal displacement. These conclusions have been adequately substantiated as a result of mathematical analysis.

This absorbingly interesting hypothesis became widely spread, and moreover there emerged its different variants. The assumption also implies a highly considerable ramified displacement of plates over thousands of kilometres (!). According to this hypothesis the most intense deformations of the earth's crust take place in the parts where the plates collide, and where there appear the mountain-folded structures (e.g. the Himalayas and the Andes). We already know that we participate in the most diverse movements: the movement of the

planet around its axis, the movement round the Sun, the movement of the Sun in the system of Galaxy, and, lastly, the movement of the Galaxy itself, together with which we rush at a breath-taking speed into the boundless space of the Universe. Today in addition to space movements of this kind we have also acquired some notion concerning more minor geological displacements together with the lithospheric plates. Now, who can refuse to be a crew-member in a voyage across the vast 'pallial ocean'?!

Plate tectonics did not leave cold many a mind and played a substantial role in the development of geology. It made the scientists concentrate their attention on the relationship between the phenomena and the global processes, the superficial and the deeper ones, which had earlier escaped our notice, and set the task of mathematical and physical substantiation of the fundamental principles of our knowledge about the Earth.

It seems as though we have approached a new stage in the development of science, viz. the transformation of geology from a descriptive science (and for this reason considered by some to be a 'second-rate' science) to a genuinely fundamental branch of studies, based on the application of the so-called exact methods. And it is not by chance that this hypothesis found a large

number of adherents, particularly among the oceanologists and geophysicists, who were its pioneers and the first and main proponents. The new theory is also supported by the tectonicists, especially those outside the USSR.

The regular pattern produced by the current hypothesis of plate or global tectonics (according to Sorokhtin and which is now incontrovertible) is nevertheless criticized by its opponents as regards its various aspects.

What can then be said about the attitude to these new ideas on the part of the orthodox proponents of fixism? The most ardent opponent of mobilism in any of its forms (and primarily plate tectonics) is the well-known Soviet tectonicist V. Beloussov, Corresponding Member of the USSR Academy of Sciences. As has already been mentioned, he proves that it is the vertical rather than the horizontal movements to the technosphere that are most important, and elaborates the idea concerning the supply of tectonic impulses and magmatic melts from the asthenosphere, where basaltic 'melts' from the underlying peridotitic mantle are accumulated. Together with the other researchers he acknowledges the most significant role of the Benioff-Zavaritsky zones in the supply of magmas and solutions into the upper horizons of the earth's crust, though he consid-

ers the dip to be of secondary importance. In his opinion they were the vertical and steep faults, which during the underthrust of the relatively compact mantle had dipped towards the continents.

An essential element in V. Beloussov's concepts is his conclusion as regards the basification of the crust and its transformation from the acid continental variety into the basic oceanic one under the vertical subsided blocks. One of the principal inferences of this scientist is the change in the composition of the mantle in the course of a certain period of time and its depletion as a result of the melting of light components and degassing. The idea pertaining to the 'depletion' of the mantle had earlier been developed by Professor S. Zimin, a geologist in the Far East.

Where is the truth then? It is impossible to wholly reject the function of horizontal displacements of the structural elements of the earth's crust; it has been substantiated by contemporary measurements too. It has most apparently been established in all the zones of different scale—from minor shifts to the most prominent displacement (the system of equatorial shifts). At the same time, however, there exists sufficient evidence as regards the stable bonds of the structures of the earth's crust in the vertical direction with the deep-seated sources of magmas and solutions. In other

words, there is also much that is irrefutable about the concepts adhered to by the proponents of fixism concerning the stability of the structures of the earth's crust, that have not undergone any marked deformation.

What are the principal controversies in the theory of plate tectonics?

One of the factors disproving the comprehensive mobility of plates is the stability in terms of time of such a large structural element as the block of the Pacific Ocean. It existed as far back as the Precambrian, or at any rate the Riphean period, when diverging from it sea basins were spreading themselves upon the surrounding continents. At that time on the crystalline basis of shields there emerged troughs, that were oriented parallel to the contemporary boundaries of the ocean. These troughs with the Riphean (Canada) and Mid-Proterozoic (Australia) masses, deposited from the sea basins, are known to exist in the marginal parts of the Pacific Ocean today. They were formed along the faults upon the more ancient Pre-Riphean or even earlier foundation of the continents, which as long ago as then had already been encircling the Pacific Ocean.

As far as the still earlier period of time is concerned, we have data concerning the stability of Pangaea in the Archean, and perhaps in the early Proterozoic period,

since the structural elements of the now disconnected shields can be reconstructed in the form of what at one time existed as large integral structures. The conclusion that there was no displacement of plates in the unified ancient Pangaea was arrived at by the Canadian scientists whose research is connected with the ancient shields, and Canadian Shield in the first place. According to Goodwin, Pangaea had the form of a crescent and was stretched along the meridian. Presumably it was fringed by the general ocean Pantalass, the residue of which is the Pacific Ocean itself. What we can assume is that the ancient Precambrian continent continued to survive in the region of the North Pole, joining Eurasia and Laurasia. Thus, we can imagine that Pangaea was spread throughout the whole of the northern hemisphere, going in some places far towards the south.

We might as well continue to regard as tenable Wegener's ideas concerning the gaping fault that separated South America from Africa and Europe from North America with the result that the Atlantic Ocean was formed. Perhaps the other aspect of this process is represented by the thrust of continental masses upon the Pacific block in the west of the American continents. In North America the movement towards the east is evidenced by the systems of scaly overthrusts of the Rocky Mountains, which

reduce the overall width of the band of Paleozoic rocks of this region. In South America it is a considerable increase in the thickness of the earth's crust, in the Andes it is up to 70 kilometres, which has occurred as a result of the 'packing' (or recumbent) of the continental crust and the thrusting movements of the American continent upon the Pacific megablock, and the rejuvenescence of the magmatic and ore formations towards the east.

Thus, the horizontal movements of the lithosphere do actually take place, though the concepts of a considerable relative displacement of continental masses are found to contradict the regular network of faults—the orthogonal ones, that closely coincide with the orientation of the contemporary parallels and meridians, and those of the diagonal variety of the north-western and north-eastern directions. The correctness of this kind of 'lattice' with regular separation from each other of large single-order faults makes it essential that we should assume this network to have been formed in the early stage of the development of the Earth and a substantial impact of these systems upon all the ensuing events: the deposition of geosynclines, the formation of folded regions, the origin of fractures (faults) with the belts of volcanism and granitic batholiths, extending over hundreds and thousands of kilometres, as well

as long and comprehensive zones. These are exactly the same directions that condition the polygonal (and not rounded) contour of the Pacific Ocean basin, which is restricted by a system of rectilinear faults.

How can we correlate the indisputable data on the stability of tectonic elements with the obvious features of horizontal displacements of continental masses discussed above? The controversy can be resolved if we imagine a single general movement of the upper geosphere with a slow turn round the North Pole and the retention of relative interrelationships between the componential blocks, which only sporadically and in some places were disturbed by the gaping faults and local shifts.

It is assumed that a single protocontinent Pangaea covered not the whole of the Earth, but mainly its northern part and embraced, so to speak, the ancient block of the Pacific Ocean. The assymmetry of continental masses was reflected in the dip of the axis of rotation, which some time later had such important consequences as the change of seasons and climatic zonality, as well as other characteristics pertinent to the assymmetrical development of the Earth. The fracturing of equatorial Gondwana can then be connected with the high linear velocity of the rotation of the Earth near the equator.

We have raised certain doubts concerning some of the principles of plate tectonics, but this does not mean that it should wholly be rejected. As has already been mentioned the main role of this hypothesis consists in that it is the first to raise the global problems of geology in general terms and tries to solve them from a single viewpoint. There can be no doubt that the horizontal displacements of the Earth's crust stated in this hypothesis are highly significant indeed. But does it mean that we actually turn away from the positions held by the proponents of fixism? Their assertions concerning the stability of the structural elements of the Earth remain doubtlessly valid which superimposes certain restrictions as regards the conclusions about the scales of the horizontal displacements of lithospheric plates. What also seems to be consistent are the views put forward by the adherents of fixism on the impact of vertically directed forces on the processes that take place in the superficial zone of the Earth. This is quite natural since what we have here is the degassing of the mantle and the uplift of melts from the depths, which cause a certain disbalance in the earth's crust. Thus, within the earth's crust we find the combination of both the horizontal and vertical movements, which are interrelated and depend upon each other.

The role of the two types of movement is taken into account by R. van Bemmelen in his hypothesis. This famous Dutch scientist assumes that the horizontal movements of the plates of the mantle take place on different levels and may be compared to the sliding of books in a pile. According to R. van Bemmelen, in the movement of the lithosphere, there occur wave-like displacements (undulations), in which their vertical and horizontal components are combined. In R. van Bemmelen's variant, who was a proponent of fixism before, and who now became a no less active supporter of mobilism theory, the elements of two extreme trends—fixism and mobilism—are brought together.

However, there may be other factors lying behind the horizontal displacements of the lithosphere. Perhaps it is the influence of the Earth's rotation, which causes the displacement of masses towards the west. Doesn't it make possible to associate the unilateral arrangement of Pacific Island arcs and the rejuvenescence of magmatic and ore formations in the eastern direction? Couldn't it be that the source of these movements of the lithosphere is in the depths of the Earth, in the region on the border of its lower mantle and the liquid outer nucleus, as is suggested by O. Sorokhtin, or in the outer nucleus itself, where the ordered rotation excites the magnetic field

and represents a d.c. generator of the Earth, its perpetuum mobile.

In the light of what has already been said the truth lies inbetween those two extreme approaches: those of the fixism trend cannot but acknowledge the important role of horizontal displacements, while the mobilists should certainly stop exaggerating the enormous scope of these displacements, since the constant character of the Earth's basic structures contradicts these conclusions.

One should be very careful in transferring the regularities, established in the young oceans, to more ancient basins of sedimentation, or the geosynclines. The conclusions about the development of oceans as a result of gaping faults, which are tenable as regards the young oceans, are presumably applicable to relatively late stages in the development of the planet, which might have been brought about by the periodic impulses of its expansion.

The idea that the expansion of oceans is compensable for by the subcontinental underthrust cannot adequately explain the scale on which the earth's crust is extended when the oceans are formed. Neither can it be compensated for by the 'congestion' of rock masses in the peripheral parts of the oceans (the Andes) and at the articulation of plates (the Himalayan Mountains). Hence, it seems to be more logical to admit a certain periodic (?) expansion of the

Earth and connect this process with formation of not only the oceans, but also the planetary volcanic belts, as well as the gaping faults of the marginal seas.

In our age of accelerated development of sciences it is difficult to predict what their nearest future could be. Undoubtedly, there will be new discoveries in geology too. The use of geophysical methods and deep drilling will make it possible to penetrate into the bowels of the Earth and the depths of the ocean. Absolute truth, though unattainable, will certainly be the aim in our endless quests.

Part VI
Mineral Resources

Chapter 16
The Mineral Kingdom

The kingdom of minerals is highly varied indeed. We know of more than three thousand minerals and mineral species, though the number of the basic ones, or those that are most widely spread, is relatively small (two or three hundred).

You all know quite a few minerals. For instance, who is not familiar with malachite, with its beautiful green patterns?

My readers can see it in the facing of the columns inside St. Isaak's Cathedral and the Malachite Hall in the Hermitage in Leningrad, and I'm sure you will not leave it unnoticed.

We know a large number of minerals from the facing of the underground stations. For example, the rose-coloured rhodonite at the 'Mayakovskaya' metro station in Moscow is well in conformity with the dark-grey marble and the sparkling arcs made of steel.

You must certainly know the quartz; and those of you who have been at the shore of the Black Sea must have learnt to distinguish semi-transparent opal, chalcedony

and carnelian in the pebbles on the shore.

Nowadays many women are highly-qualified mineralogists and can distinguish the rose-coloured tourmaline which often ornaments the rings (it should be noted that tourmaline of this colour is rarely found in nature; the type that is preponderant is either black, dark-green, or blue).

Quite a few of us are undoubtedly aware of such stones as emerald and ruby. Both these minerals are already produced by artificial means. For instance, the ruby stars of the Kremlin were created according to the designs elaborated at the Institute of Crystallography of the USSR Academy of Sciences, whereas artificial emeralds are received at high temperatures and pressures at the Siberian section of the Academy of Sciences. In their time diamonds presented a unique value; today they can be produced artificially for technical purposes. Of course you know such stones as amber (the fossil resin of ancient trees), the blue aquamarine (beryl), the smoky topaz and the recently discovered chromite which has already become popular with fashionable women.

Beautiful stones have always attracted people. In their time they were also attributed miraculous properties. People thought that some of them could cure diseases, others were supposed to possess the charm to draw the beloved person to oneself, and

still others were meant to drive away any woe and affliction. That is why in the olden times every nation had its own legends and superstitions connected with the beautiful stones. Even at present they continue to please us, while their various products, made by skilful artists can be seen in the largest museums of this country, and primarily in the Hermitage.

Stones are not only enchanting articles of beauty; they are also a necessity of the first importance. It is precisely with the use of stones that the development of mankind had been connected. Beginning with the first tools, such as a stone tied to a stick, stones had become most closely associated with man's activity. Even the pre-historic man could distinguish a hard stone among the other stones and could masterfully carve it so as to make sharp knives, axes and other implements of labour. This was the Stone Age that covered millions and millions of years!

An enormous role in the development of material culture was played by the discovery of means of producing and developing metals. The brightly shining native copper that is found in the surface outcrops of copper ores had early drawn to itself the attention of man. It was a soft metal that was sufficiently pliable to serve as the material for manufacturing purposes. Dishes, knives and other tools were made of

it. Copper could have been melted by chance. Bright oxidized copper ores of the blue and green varieties had certainly drawn the attention of people, who would often bring them to their own dwellings, and pieces of oxidized ore must have often got into the huge bonfires.

Later people also learnt how to produce bronze. It was a chance discovery too. In some of the pieces of oxidized ore in addition to copper there were other metals, such as tin. zinc, and antimony. The melted alloy was found to be harder than copper; it was bronze itself. Thus, presumably, independently and not coetaneously bronze was discovered in different parts of the world, which marked the beginning of the Bronze Age (4 thousand years B.C.).

And now the iron? It was known very long time ago and found in the meteorites—'the stones from heaven'—or in the nuggets. It was valued more than gold. It must have been in the Caucasus that people learnt to melt iron. The culture of this metal had been developing not at the same time and independently in different parts of the world, though exchange of experience had always existed as such.

The history of the development of our knowledge of stones, primarily of the precious stones and gold, goes back to the remote prehistoric period. Choosing stones for his tools, man did pay attention to the

nuggets of gold shining like the Sun, and the beautiful multicoloured stones that were collected for various decorations.

Let us recall the myths about the Argonauts who started on their voyage from Greece to the shores of Colchis in quest of golden fleece. In Egypt gold was known long time before copper (5-6 thousand years B.C.). It was recovered in Arabia, on the shores of the Red Sea, and in the valley of the Nile. The culture of gold products came from the region of the Mediterranean Sea to the Black shores via Byzantium. Unique articles of gold found in the Scythian places of burial testify to the high degree of mastery of those who had made them.

Thousands of years ago large quantities of gold were accumulated in the copious treasures of the ancient kings. Thus, according to the legend, the seafarers of Chiron, the King of Tyre (the old Phoenician city which exists even now on the territory of Lebanon) brought much gold from the country of Ophir. Queen of Sheba brought Solomon a great amount of gold and precious stones from Lybia as a gift.

It is known that King Solomon had a cup made of a huge crystal of emerald. This cup is now kept as a sacred bowl in St. Lawrence's Cathedral in Genoa. We also know that Nero watched the performances of gladiators through a crystal of emerald. This cannot but serve as evidence

that stones were widely spread in the countries of ancient civilizations. There also exist legends and works of fiction based on an historical material. One of them is the poetic work of the Russian writer Alexandr Kuprin 'Shulamite'. The author described stones that were known thousands of years ago, and the superstitions that were connected with them.

Great were the contacts between the merchants of the ancient states. These ties lay across the seas (the seafarers from Tyre) and land. For instance, the delivery of nephrite was from China: ruby, diamonds and sapphires came from India, and perhaps through Iran (Persepolis) turquoise was exported from Afghanistan. We know about the later journeys to India, Iran, Babylonia, and Ethiopia from the historical records. Thus, we can actually imagine the delivery of stones from faraway countries. Stones were said to have magic properties and power over people. Red stones (ruby) were the stones of turbulent passions: love, wrath, blood; the blue ones (e.g. sapphire) were the stones of calm.

But precious stones were connected not only with superstitions. Properties of minerals were studied too. Thus, on the threshold of the new era the Roman scholar Pliny the Elder wrote: 'There are many reasons why smaragdites (emeralds) are rated the third in value after diamonds and

pearls. One would seek in vain for a colour that would be more pleasant to behold, since it is with pleasure that we also look at the green grass and the leaves in the trees, but smaragdite appeal to us most, as there is nothing green that is greener than they.... They spread their lustre far away and seem to colour the air beside them. They change not in the sun, neither do they change in the shade, nor under any light and are always wonderful, always shining bright, and judging by their thickness, possess an unhindered transparency, which we cannot help admiring in water either.'

This is where we already see the description of the main physical properties of a mineral—colour, lustre, and transparency.

We have been speaking of the propagation of stones and the information about them in the countries of Mediterranean civilization. However, the culture of the stone itself had come earlier from the East, in the first place from India—the home-country of precious stones: ruby, sapphire, and diamond. And it was there that the first special books about the stones had been written.

In China the cult of nephrite has existed for a long time. It is a remarkable stone which issues a warm light, and though hard is nevertheless viscous enough to be handled by the sculptor's chisel. We can see the sculptures of Buddhas, various animals,

vessels and vases with a highly complicated ornament in the Nephrite Museum in Singapore. The nephrite here is of different colours: besides the common greenish variety, we can also find the bluish, light-grey to ash coloured, white, red and black types of this stone. In other words, nephrite has borrowed all the colours of the rainbow. It is a very rich collection of Chinese nephrite which exhibits the works of art of many generations of the unknown sculptors and the high culture of their work with the stone to say nothing of that subtle artistic appreciation which has been inherited by the sculptors from the olden times.

The ancient world (Greece) had made itself famous with its marble sculptors. With a venerable feeling the author went up the high steps that lead to the Acropolis. Suffice it to say that the great men of the past—Aristotle, Heraclitus, and Socrates—treaded them too. In the centre of Acropolis stands the renowned and grandiose Parthenon (the temple of the goddess Anthena). It is majestic and yet does not look ponderous owing to its rigid proportions. We see the straight columns before the façade, and above them on the pediments friezes with the sculptures depicting the courageous struggle of the strong and handsome people against the centaurs. Right in front of the building there lie many fragments of marble monoliths—the remains of dilapidated

buildings. The snow-white marble transparent in its thin chippings surrounded us everywhere. How skilfully the people could choose and handle the stone! But ...

Sic transit gloria...!
And with no mercy from the sultry air
The temple slumbers in euphoria
With white plates everywhere...

After that I visited Italy, and also found myself in a fairyland of marble, though already of the epoch of Renaissance. In the great masterpieces of Michelangelo and other sculptors the austere and realistic art of the ancient Greeks was resuscitated.

Now, let us go back to the subject of our disquisition. As has previously been mentioned, the culture of stone formed the basis of the progress of not only civilization, but also of art and science.

The work with the stone (the collection of stones and the study of their properties) had led to the development of geology and its filial science—mineralogy. The inception of exact mineralogical research coincided with the period of early Middle Ages, when scientific attainments in Central Asia had reached a high level of development. It was in that part of the world that such outstanding men of science as Avicenna and Biruni (the one who described so many minerals) lived and worked.

Avicenna (Ibn Sina) the scientist, philosopher and poet, in his poem *At the Market*

in Bukhara made fun of the quacks' extortions, who were wont to cure the patients, promising to cure them of all the illnesses with the help of precious stones.

You go to the market where amethysts are sold,
If your hands are aching, and the eyes are old,
The vociferous clerk and the old magician
Will explain to you why you need no physician,
That your health is contained in the precious stones,
With the Power of Allah that each of them owns.
Let them find their place on your finger and turban,
And to use them well try to give them to no one!
You wear them on a string, and put them on your neck,
The agate guards the chastity of maidens, don't forget;
The secret of Allah the king magician did reveal,
For leprosy and wall-eye it is the beryl,
The turquoise will keep you safe upon your horse,
And will lend your eyesight extra force
And your face will be bright as the fair maiden's curl,
With the help of carnelian, sapphire and pearl.

We can find here the mention of the very same stones that were known in the ancient Izrael, and even their 'professional qualities' in the legends had been preserved (e.g. the turquoise tames horses).

The materialistic scientist Avicenna expressed his sceptical attitude to the futile dreams of the alchemists that gold and mercury could be received through artificial

means and their quest of 'philosopher's stone'. However, he did not fail to give an objective assessment of the practical value of the works of those who were the first to lay the foundation of chemical studies. This is reflected in the dialogue between Ibn Sina and the alchemists in *The Ballad of Mercury*.

The dialogue begins with the words of the alchemist:

I can produce the metal from an oxide:
See for yourself how docile it's with me...
Ibn Sina read the text minutely written
And nodded, gratified a scientist to see.
What he beheld was quite a different dawn,
The realm of chemistry that now was to be born.
His love for it was not in vain
Its elements be used to kill the patient's pain.
For long he tried to delve into the substances
That had no life and brought no cure.
To study mercury and manganese and try to find
The combination magically pure.
To stay amidst the cauldron and try them all.
From what has been written and that could
now enthral.
The witchcraft was no waste of time
And fulminate of mercury was found instead of
gold
An irresistible explosive yet untold.

The ballad ends on a tragic note: the researching alchemist gets killed when the fulminate of mercury that he had received explodes. Ibn Sina did not manage to stop him in time: 'Death as a price for quest is wonderful indeed!'

In the works of the alchemists who cherished a futile hope to produce gold and discover the 'philosopher's stone' a clear-cut realm of chemistry was being initiated. It developed further when minerals were studied and experiments connected with their decomposition into constituent parts were carried out.

The new era in the development of the scientific study of minerals came in the sixteenth and seventeenth centuries. It was in the ore mountains of Saxony that there lived and worked at that time the physician and naturalist Agricola (Bauer). As was the case with the famous Greek physician Theophrastus, he got interested in minerals when studying their curative properties. Then it became a serious research of the minerals in the silver ore mines in Saxony. Agricola created a classification of minerals and a theory pertinent to the origin of minerals from the solutions or 'juices' that came from the bowels of the Earth.

The mineralogical and geological investigations of the deposits in Saxony received further development after a mining school was organized. It then received the name of Freiburg Mining Academy—the first special mining educational institution in the world. At one time the great Russian scientist Lomonosov worked at that academy and in Saxonian mines. It was from there that the eminent scientist with en-

cyclopaedic knowledge derived the interest to geological studies and the material for his books *On the Layers of the Earth*, and *On the Origin of Metals as a Result of Earthquakes*.

Lomonosov did very much for the development of mineralogical studies and the quests of ores in Russia. It was his idea to write the book *The Mineralogy of Russia*. His appeal to those concerned with the mining industry found a major response and initiated the collection and then the classification of minerals.

As far back as the seventeenth century copper and iron ores had already been discovered in the Urals. This was followed by the finding of silver-and-lead ores of Nerchinsk, the Baikal region and the Altai. Lomonosov encouraged quests of ever new deposits. All that he said did not remain profitless. In the Urals, now the village of Murzinka, precious stones were discovered in the middle of the eighteenth century. They included green emerald, blue aquamarine, and rose-coloured tourmaline; in Siberia and Transbaikal region lazurite was found, while the Sayan mountains yielded nephrite. Riches began streaming into the treasures of the Russian emperors. They now came not from foreign lands, but from Russia itself, and were worn by the ladies belonging to the class of aristocracy.

Some of the stones received even the Russian names, as, for instance, sibirite (uvarovite). Precious and coloured stones ornamented the majestic palaces and churches of St. Petersburg.

Mineralogy started to develop too. Lomonosov's untimely death prevented him from writing the work on the minerals of Russia. But the impulse was given indeed. Since 1763 lists of minerals had been compiled in Altai with their detailed descriptions. This was exactly what can be called the beginning of mineralogical research in Russia. Later the same kind of work was also initiated in the Urals. It was supported by the country's mining industrialists. Minerals were now collected on a wide scale. This was followed by orders of administration to buy the stones of the miners. In the eighteenth century there was even a special mineralogical shop in St. Petersburg.

In 1774 mining schools were established in Ekaterinburg and St. Petersburg. They were to train specialists who would head mining enterprises. Soon the school in St. Petersburg was transformed into a paramilitary cadet mining corps which later became a Mining Institute. It was the second higher mining educational institution in the world after the Freiburg Academy. A mineralogical museum was almost immediately organized at that school. It became the recipient of mineral specimens from all

the mining regions of Russia. Large foreign collections were also bought. This was how the foundations of mineralogy in Russia were laid—the science that emerged on the basis of the generalization of the experience of miners and the knowledge about minerals that had been accumulated in mining engineering.

As early as the nineteenth century mineralogy gave rise to the scientific study of crystals, or crystallography, in which mineralogy was correlated with physics, chemistry and geometry, and later geochemistry—the synthesis of geology and chemistry.

At present the current mineralogy went a step higher. New methods and facilities are employed. If prior to this day the natural scientists were describing the properties of minerals, they were now interpreting these properties, proceeding from what they exactly know about the composition and structure of minerals.

It cannot be but mentioned that many properties depend on the inner structure of a mineral. They also depend on the arrangement of atoms in a crystal and the form of 'cells' of its geometrical inner structure. For instance, in the cubic crystals of common salt (NaCl) the atoms of chlorine and sodium are alternately situated in the 'nodes' of cubes of the crystalline lattice, and the outer form of crystals is also ex-

pressed by cubes. We find the same structure and form of crystals with lead lustre, e.g. galena (PbS), where the atoms of lead and sulphur alternate. But in some minerals of more complicated composition and inner structure the outer facing of crystals is also much more intricate. We may as well remember the polygonal crystals of garnets!

Other forms of crystals can be found too: e.g. elongated prismatic varieties or those that are platy, which is also connected with the inner structure of minerals. Elongated chains, characteristic of many silicates, form tetrahedra of silica (SiO_2), with which atoms of certain metals are combined. Prismatic crystals can be of various form of cross section, e.g. hexagonal (the hexagonal group—beryl, tourmaline), tetrahedral (the tetrahedral group—cassiterite), and rectilinear (the rhombic group—pyroxenes).

The inner structure influences many properties of minerals. Let us take, for instance, two minerals of one and the same composition—diamond and graphite. Both of them consist of one element—carbon. And yet how different they are as far as their properties are concerned!

Among the minerals diamond reigns supreme. It is the hardest (10 points on a ten-point scale), transparent, and sparkling mineral. These properties depend on the inner structure. It possesses the greatest

density, 'compactness' of the inner structure—the arrangement of the atoms of carbon in the crystalline lattice. This is also reflected in its outer facing, the increased specific weight, hardness, as well as in the so-called adamantine lustre: the interplay of light during the reflection from the inner layers due to the lowered velocity of the properties of light in a crystal.

The graphite, however, which is also an example of pure carbon, finds its place at the other end of the scale of hardness. Its hardness is the lowest (1), which is connected with the characteristic features of its loose inner plastic structure. Graphite is opaque and has a metal-like lustre. This shows how different the two minerals—diamond and graphite—with the same kind of composition can be! Moreover, these two minerals are found under different conditions: the formation of diamond requires a high pressure and substantial depths, while that of graphite calls for high temperatures at the contact of granitic massifs or regional metamorphism.

Minerals are also distinguished by their colour, which often depends on their composition. For instance, copper (malachite), nickel and chromic minerals are green, manganese varieties (with the protoxide of manganese) are rose-coloured, and the lithium one are also of that colour.

Some minerals are of various colour. Garnets can serve as an example: the magnesium ones—the dark-red pyropes — are known to those women who are fond of decoration by the remarkable crystals that come from the metamorphic masses and placers of Czechoslovakia; the ferriferous garnets are brown, the calcic ones are yellow and green, those of the chromium variety are thickly green, and the manganese garnets are rose-coloured. Each variety has its own name and conditions in which it was formed. For instance, the magnesium garnet, or pyrope (the satellite of diamond) is formed under high temperatures and pressures in the depths of the Earth. The green chromic garnet, the uvarovite is situated in the deep-seated ultra-basic rocks that are rich in chromium. The calcic garnet—grossularite—is found in the metamorphosed limestones at the contacts with the granites. Hence, the composition and the colour of garnets cannot possibly be divorced from the conditions of their formation.

Sometimes the colour depends on subtle admixtures. For instance, besides the colourless corundum (Al_2O_3) we know its coloured varieties: the red ruby and the blue sapphire. There are cases when the colour of minerals is influenced by the defects of crystals, while in other instances it is the impact of the inclusions of radioactive minerals.

The use of new methods of research, spectral, X-ray, as well as X-ray and X-ray chemical facilities make it possible to determine not only the basic composition of minerals (the principal components), but also the inconsiderable admixtures that are of no minor importance. It also becomes possible to establish what form the elements of the admixture have, i.e. whether they fill the space between the main atoms in the lattice of a mineral, replace some of the atoms, or, lastly, give rise to the formation of microminerals—the foreign, captured inclusions.

The mineral kingdom is highly complicated, and there is much to be done to get to the bottom of it.

I like to visit the mineralogical museums. Their number is very great! We can find them not only in large cities, but also at the mines, as, for instance, at the oldest mines in Czechoslovakia, Guanajuato in Mexico, and Dalnegorsk in Primorye.

The variety of minerals is practically boundless! I carefully hold the entangled felt of very thin hair-like crystals of jamesonite (the combination of lead with antimony and sulphur) at the museum of the oldest mine in Prshibram in Czechoslovakia. This sample comes from the upper horizons of the mines that were exploited ong time ago. I try to remember the rarest mineral of selenium—guanajuatite—at the

museum of the Guanajuato gold mine in Mexico.

And how can all those crystals at the Dalnegorsk museum in Primorye leave anyone cold, even if the person has nothing to do with mineralogy. Calcite, for instance, seems to be an ordinary mineral; and yet we find it here in the form of beautiful and multifarious crystals! I remember that one day a certain worker brought to the place where we were stationed a whimsical mushroom, made of calcite. We bought it with no little pleasure. Today it is one of the main treasures at the Dalnegorsk museum. How really wonderful nature is!

And what extraordinary impression is produced upon us by the 'natural museums', which we see in the mines, that with each metre reveal to us ever new parts of the fairyland built of stone. The polymetallic Dalnegorsk deposits of the Far East with their unique crystals of various minerals cannot but remain indelible on the memory of anyone who has visited those places. The deposits are situated among the limestones. They are either the sinuous, tubular irregular deposits, or flat lenses. The main part of ore bodies everywhere finds its expression in the dark-green mineral known as hedenbergite (the silicate of iron, calcium and manganese from the group of pyroxenes). Hedenbergite gives rise to enormous spherical separations with the cross section,

measuring up to one metre and more, and which are closely attached to each other, thus forming scalloped zones of radiate-fibrous dark crystals. Between the rays of the dark hedenbergite we can see the silvery flashes of the little bands of light and sparkling galena, the golden streaks of chalcopyrite, and the black stripes of sphalerite. All this produces an enchanting impression, especially in the light of electric lamps in the spacious underground chambers.

But what is particularly interesting and varied in form is the crystals of minerals that grow on the walls of voids. This is where we can see druses, a host of crystals of galena, sphalerite, and the remarkably variegated forms of the crystals of calcite. How truly wonderful the crystals of calcite are! Among them you can easily distinguish figures of the type of pointed peaks or flat crystals which the miners call 'heads of nails', or complex branched forms that have received the name of 'heads of cauliflower'. These appellations concocted by the miners most precisely convey the peculiarities of the crystals that have such unusual form.

The scientists study the conditions relevant to the formation of crystals of different form and point out that in due time together with the drop in temperature of the solutions the forms of crystals have undergone various changes. In order that we could imagine everything that is unusual about this elfin

pattern of underground palaces, it should be said that the cross sections of those chambers or voids (they are called vents at the mines) sometimes reach several metres. In a large number of cases they have the form of narrow chinks, rounded or tubular cavities, that do not easily lend themselves to access and are, moreover, dangerous. The number of these vents was particularly great at the upper horizons of the mines.

Specimens of Dalnegorsk crystals have now acquired a world renown. They are exhibited most profusely in the largest mineralogical museums of the USSR and elsewhere.

Minerals yield all the elements that are used in inorganic chemistry. The pioneers of this branch of studies were the medieval alchemists, who futilely worked in their laboratories, trying to artificially receive gold and discover the 'philosopher's stone'. However, in spite of the erroneousness of their concepts, the nature of many chemical elements and compounds became known in the course of their investigations. By the beginning of the nineteenth century the rudiments of chemistry had already been founded. In the later period they enabled the great Russian scientist Dmitri Mendeleev to create the periodic system of elements. Mendeleev's prognostications concerning the discovery of new elements have been confirmed. For the development

of geochemistry and then biochemistry much has been done by the outstanding Soviet scientists V. Vernadsky, A. Fersman, and A. Vinogradov.

Chapter 17
Mineral Raw Materials and Technical Progress

This chapter is more technical than geological since the subject of our discussion will be the multifarious character pertaining to the use of mineral resources.

There are many treasures in the bowels of the Earth, and it is they that the geologists try to discover. Our life as such is most closely connected with the use of natural resources. Look at all those things that surround you: the house in which we live is built of stones, bricks, and concrete—the raw material for which is provided by the Earth. The cars that are indispensable for industrial and private use are made of metals, the ores of which are recovered from the deeper regions of the Earth.

The whole life would come to a standstill if the resources of such metal as tin were exhausted: one needn't dwell too long on the fact that the alloys of tin are used for ball-bearings which are essential for any kind of mechanism, since without the alloys of tin it would be impossible to produce cars, electric trains, instruments, and there

would be a sufficient decrease in the output of tinned foodstuffs. In other words, even such an inconspicuous metal as tin proves to be a highly important unit in the system of technology.

And what about oil? We might as well recall the energy crisis which affected so many countries, and it will become quite apparent how much everything depends on the combustible fossils, the reserves of which are restricted and unevenly distributed in the world.

The whole history of mankind and its civilization is inseparable from the use of mineral riches.

Not all the metals, however, were employed for industrial purposes at the same time. The scope of their use has been made ever wider. Together with bronze people started using tin, tungsten (wolfram) was as far back as the Middle Ages regarded as a hazardous admixture to tin ores. Nowadays tungsten is widely used in the production of refractory kinds of steel, filaments for the electric bulbs, etc.

The recovery of lead goes back to rather an early period. It was used for the manufacturing of bullets, whereas now it has become a very useful material for the screens that protect us from radioactive radiations. But zinc—the permanent satellite of lead—had not found any application for itself for a long time. Even today it is a kind of

foster-child in nonferrous metallurgy. It seems to be fit only for the production of bath tubs for children, pails, and zinc wash. But the cost of admixtures of rare elements contained in the sulphide of zinc, i.e. indium and cadmium—can be correlated only with zinc itself! Hence, there is every reason for us to say that zinc ores present no minor value.

The revolutionary role in technology of the discovery of radioactive, rare and rare-earth elements is a fact of common knowledge. Practically all the elements of Mendeleev's periodic table are now used by man.

Our disquisition of the mineral kingdom would be incomplete if we failed to characterize the ores of the principal mineral resources, their types, the conditions in which they are formed, and did not bring to light the fields where nowadays various types of mineral products are used, all of which are bound to present special interest for the readers.

At this point in our disquisition we shall not follow the generally accepted genetic system of description and divide all types of raw materials according to technical features and concentrate on the ferrous, nonferrous as well as rare metals, which serve as an important addition in various fields of metallurgical production processes. Then, we shall touch upon the most significant nonmetalliferous metals.

One way or another people use all the rocks and minerals that have been found in the Earth. According to the data that were provided by A. Vinogradov, the following elements may well be considered to be predominant in the earth's crust (their content is given in per cent values): oxygen (49), silicon (27), aluminium (8.5), iron (5), calcium (3.5), potassium (2.5), sodium (2.6), and magnesium (2.0). These elements enter into the composition of silicates and alumosilicates, which comprise the earth's crust. It is precisely the 'firmament' upon which we live and within which all the processes of migration and concentration of matter take place. We have already mentioned that the Earth's deep-seated shells are distinguished from the earth's crust by their composition. They have more iron and magnesium as well as diverse ore elements, including the 'concentrate' of metals—the iron-and-nickel metallic nucleus, which, as is assumed, is situated in the centre of the Earth.

The deep-seated shells are the source from which many ore elements enter the earth's crust. In the earth's crust the other elements, besides those eight that have previously been mentioned, play an evidently minor role. Their content is measured in tenths, hundredths and thousandths of one per cent and even less than that. Doesn't it seem strange that such a common ele-

ment as manganese comprises only 0.09 per cent, nickel—0.01 per cent, while lead, on average, not more than $1.5 \cdot 10^{-4}$ and its permanent accessory zinc is characterized by even a smaller figure of $1 \cdot 10^{-5}$. Approximately the same quantity as that of lead is typical of uranium ($2 \cdot 10^{-4}$), which is rather infrequently found in the deposits. Now, the content of radium in the earth's crust is extremely small—only $n \cdot 10^{-10}$—which is less than a tenthousand billionth part of it.

That is why it is so important to have high concentrations of metals in the deposits, where their contact is many thousand times greater than the average content in the earth's crust. Thus, the deposits of metals may well be regarded as the nature's rarest gift.

What forms the basis of contemporary technology is ferrous metals. In the main they are siderophile elements ('sideros' meaning 'iron').

Most of the elements belonging to this group of iron form the eighth group of Mendeleev's periodic table and have analogous chemical properties. They are constantly found together. This includes iron, nickel, cobalt, and platinum. 'On friendly terms with them' are the representatives of other groups too; for instance, titanium and vanadium that are situated in propinquity with iron in the fourth series of

Mendeleev's table. The characteristic feature that is common to these elements, as well as the minerals that are formed by them, is the bond with the ultrabasic and basic deep-seated rocks, which penetrated into the upper shell of the Earth along the faults. But at the same time the very same metals also take part in the superficial processes, in particular the sedimentary ones, giving rise to marked accumulations in the sea basins.

Iron is a widely spread element. Its quantity in the earth's crust measures several per cent, though it is recovered from the rich ores with the content of not less than 25% of the metal.

Types of iron deposits are highly varied. Those that are of the first importance are the so-called ferruginous quartzites—the finely-banded rocks, in which the black little bands—the iron minerals magnetite (Fe_3O_4)—magnetic iron ore and to a less degree hematite—red iron ore (Fe_2O_3)—are interlayered by the ribbons of light quartz. Deposits of this kind comprise many billions of tonnes of iron ores and are known mainly in the ancient masses the age of which is two and more billion years! They are developed in the ancient crystalline shields and platforms: in the USSR—on the Russian platform (the Kursk magnetic anomaly, Krivoi Rog), on the Siberian platform and its framing (Yakutia).

They are copiously spread in North and South America, in the western part of Australia, in Africa and India. The reserves of iron ores of this type are practically boundless—30 trillion tonnes is really an astronomical figure!

It is assumed that ferruginous quartzites were formed under the activity of iron bacteria in the ancient basins at the expense of iron that entered the solutions from the marginal elevations, and perhaps in the hot deep-seated solutions too.

The sedimentation of iron ores is also taking place at present, and, in particular, we can even study these processes in the lakes and seas—the now existing 'natural laboratories'.

Over the past few years segregations of iron concretions (nodules) have been discovered on the ocean floor. They enclose enormous reserves of not only iron, but also of such accessory elements as manganese, nickel and others.

Speaking of the types of iron deposits, it is impossible not to mention the so-called contact, or skarn deposits which are situated on the boundary (in contact) with granitic rocks and limestones and are formed at the expense of solutions that come from the magmatic body. Deposits of this type are composed of rich ores, and they have long been known in the Urals. I saw these deposits myself, e.g. the Magnitnaya, Bla-

godat, and Vysokaya have now become huge ditches. The ore here is produced by means of open cast mining, and with some of the deposits the process has been going on since the days of Peter the Great!

There seem to be not many iron minerals. The most important of them are: magnetite, hematite, as well as different varieties of brown iron ores, and siderites (carbonate of iron). And what diversity of the types of minerals are yielded by these minerals!

One of the characteristic features of magnetite is its high degree of magnetization, which helps to conduct the exploration of ores with the help of magnetometric geophysical methods. These properties of the magnet, as the general ability of iron to be magnetized have been known since the ancient times in China, where thousands of years ago they invented the compass, which was of great service to seafarers and travellers. It was by the declination of the compass's needle that the Kursk magnetic anomaly had been discovered.

According to the conditions of formation and technical application manganese has much in common with iron. It usually performs an accessory function in relationship to iron in sedimentary ores and ancient metamorphic deposits. As is the case with iron, it is the basis of ferrous metallurgy and is used in manufacturing high-quality kinds of steel.

Ferrous metals also include chromium. Its principal mineral—chromite—forms black complete masses and impregnations of crystals in ultrabasic rocks, chromitic deposits, as well as the massifs of ultrabasic rocks enclosing them, are found in the zones of deep faults. The ore-bearing magma originated from the mantle, from the subcrustal depths. The deposits of chromites are known to exist in South-West Africa, in Philippines, Cuba, and in the Urals.

Chromium is used in metallurgical industry to render steel an extra degree of hardness, in chrome-plating the surfaces of metals and in the production of paints. It adds green colour to the compounds.

The same technical group comprises titanium. It is recovered from the basic magmatic rocks in the form of ilmenite ($FeTiO_3$) and from the placers that are on land and are very widely spread on the sea benches and shelves (Brazil, Australia, India) where titanomagnetic, ilmenite and rutile (TiO_2) serve as its source.

Titanium is employed in the production of special kinds of steel. It is a heat-resistant and light metal.

Of no minor importance either is vanadium—a frequent associate of titanium in deposits and placers, which is used for the manufacturing of especially strong kinds of steel that are necessary in the production of armour and shells in automobile engi-

neering and atomic power installations.

Nickel and cobalt also belong to the family of iron elements. They are more often found in basic and ultrabasic rocks, which can be said particularly of nickel. It gives rise to large deposits in South-West Africa, in the Kola Peninsula and in the region of Norilsk. These are the magmatic deposits. Sulphides of nickel have been crystallized from the magmatic melt that came either from the mantle, or the hot aqueous solutions.

A special type is represented by the residual deposits of nickel, which are formed as a result of the weathering of nickel-bearing basic rocks, as, for instance, basalts and gabbroids. In this connection there emerge oxidized minerals of nickel in the form of loose greenish masses. The very same residual ores are enriched with iron, and this helps to employ them for the manufacturing of iron-and-nickel alloys. In the Soviet Union deposits of this kind are found in the Urals, though they are especially widely spread in the tropical zone, e.g. on the islands of Indonesia and the Philippines, where the oxidation of rocks on the surface is very intense.

Thus, we see that according to technical application, the associations of iron belong to various groups of Mendeleev's periodic system, which does not prevent them from 'functioning' together in metallurgical pro-

duction. Iron has a large number of 'assistants' in metallurgical industry. Among them no minor role is attributed to rare metals, which will be discussed some little time later.

The importance of iron-ferrous metals for industrial processes can hardly be overrated. A large number of them are geochemically referred to the group of chalcophiles, or those that are related to copper ('chalcos' meaning 'copper'). They are: copper, lead, zinc, molybdenum, and bismuth. In natural conditions these metals form compounds with sulphur—the sulphides.

The greater number of minerals of nonferrous metals was deposited from the hot aqueous solutions: the most important of them for copper include chalcopyrite ($CuFeS_2$)—an aurous mineral, bornite (Cu_5FeS_4). The purplish mineral and a permanent associate of chalcopyrite, as well as the black sooty chalcocite (Cu_2S), which can be found in the upper part of many copper deposits.

The deposits of copper are highly varied. What has recently acquired great significance includes the poor impregnations of ores of the so-called porphyritic type, which are often deposited in vent funnels. They originated in hot solutions that were issued from the deep magmatic hearths. The reserves of these ores are tremendously large,

particularly in South and North America. Large deposits of this type can also be found in the Soviet Union (Kounrad in Kazakhstan and Almalyk in Uzbekistan).

Sheet deposits of copper ores which are formed during the volcanic eruptions on the sea floors are also very important. This is the so-called pyritic type, in which copper pyrite, or chalcopyrite, is found together with iron pyrite. For a long time these deposits had served as the main source of ores in the Urals.

And lastly, no minor role should be attributed to the so-called cupreous sandstones, which contain the minerals of copper. This is the type which covers Dzhezkazgan in Kazakhstan, Udokan in the Chita region, and the largest deposits of Katanga in Africa.

The deposits of the inseparable lead and zinc have their own specific features. The main mineral of lead is the lead lustre, or halenite (PbS), the mineral of silvery-white colour in the crystals of cubic form.

The main mineral of zinc is the zinc blende, or sphalerite (ZnS). This mineral is called blende for the reason that it does not seem to possess any ore qualities. Its metallic lustre is not characteristic of ores, and is more adamantine at that. The colour, however, ranges from black to brown and cream. As has already been mentioned, these two minerals (halenite and sphalerite)

are constantly found in association with each other.

In a large number of cases silver, bismuth, arsenic, and copper are found together with lead and zinc in ores. That is why lead and zinc deposits are called polymetallic. These deposits are formed from the hot aqueous solutions and are particularly often found in the form of deposits and veins among the limestones that are replaced by a sulphide ore.

As everyone knows, the use of nonferrous metals is very extensive (e.g. in machine-building industry, military engineering, and other fields of technology).

Such rarer metals as tin and tungsten (in practice they are now referred to the group of 'nonferrous' metals) constitute a group of their own. These metals are discovered in the form of oxygen compounds: tin—in an oxide cassiterite, or tin stone (SnO_2), tungsten—in the salts of tungsten acid: wolframite ($FeMnWO_4$) and scheelite ($CaWO_4$). Minerals of these elements are often found in the quartz veins among granites or in their proximity. The sparkling black or brown crystals of wolframite are markedly distinguished against the background of white quartz. Sometimes they can also be found in other types of deposits: scheelite at the contact of granites with limestones in skarns, and cassiterite in sulphide veins.

Oxygen compounds bring about a large number of the so-called rare metals: lithium, rubidium, caesium, beryllium, niobium, and tantalum. They are often found in pegmatitic veins. The ancient Precambrian pegmatites (Africa, Brazil, and Canada) are particularly rich in them.

What acquires great importance at present includes light metals—aluminium and its lighter relatives—magnesium and beryllium, which A. Fersman called the metals of the future. These competitors of the almighty iron are destined to replace it in many fields. The said metals and their alloys are widely used in technology, particularly in airplane industry. The building of rockets, and in the production of borehole pipes, i.e. everywhere where light metal is required.

As is known, aluminium is very widely propagated in the earth's crust, and it will be possible to receive it from any of the alumosilicate rocks that are rich in this element. Until now, however, the traditional aluminium raw materials are bauxites. They consist of aqueous compounds of alumina, which are formed either by means of sedimentation in the sea basins, or during the weathering of alumosilicate rocks.

Quite recently the method of receiving aluminium from ancient crystalline schists formed under the metamorphism of argillaceous deposits as well as from alkaline mag-

matic rocks has been elaborated. Thus, the problem of finding means of recovering aluminium has never cropped up before mankind: the amount of this metal is more than enough for all the coming generations. What is still required is the technology of its production and the power for creating adequate power-consuming branch of industry.

Things are quite different with beryllium. It is a relatively rare metal and enters into the composition of beryll and other minerals with which we have already become acquainted and which can be found in high-temperature deposits, in pegmatites, as well as in the veins that are formed from the hot aqueous solutions. This valuable metal is used in special alloys for the manufacturing of X-ray tubes.

Nowadays the complex use of mineral resources is ever on the increase. For instance, coal yields rare elements: mainly the extremely valuable germanium. The lead concentrates produce silver, bismuth, and antimony. In the lead lustre the latter become responsible only for an inconsiderable admixture, though on an enormous scale of the melting of lead ores they comprise a highly important addition to the recovery of these valuable elements from their own minerals.

Germanium, indium, cadmium and gallium are recovered from zinc concentrates.

They form a very inconsiderable addition to zinc blendes, where in the crystalline lattice they replace the atoms of zinc, by occupying their place. And yet, irrespective of their very small content, it is precisely the recovery of these little admixtures from zinc blendes that serve as the principle source of their production.

Their value is very great indeed! For instance, cadmium is used in the production of atomic reactors, accumulators and low-melting alloys. Owing to this particular quality gallium (the melt point of which equals only 30°C) is employed as a substitute for mercury in the thermometers. Cadmium together with tin and bismuth yields Wood's alloy with the melt point of 70°. Indium, when added to silver, gives it a marked lustre, and in the alloy with copper protects the ship from corrosion in sea water. Germanium is used in the production of semi-conductors.

An element like selena is not often found in independent minerals, but is present in pyrite and other sulphides in the form of an extremely small admixture and occupies the place of sulphur: it is used in manufacturing semi-conductor optical instruments, binoculars and telegraphic apparatuses, as well as colourless glass. Rare types of alkali, recovered from the micas (rubidium and caesium) are used in the production of photoelements.

What acquires an ever-growing function includes the new combinations in alloys. For instance, the alloy of vanadium with titanium, niobium, tungsten, zirconium and aluminium is used in the production of rockets and in atomic technology, while compositional new materials are also being manufactured from mineral raw materials.

Since time immemorial minerals have been employed as dyes. The most ancient artists of the Stone Age used ochre when painting wild animals—rhinoceroses, mammoths as well as scenes from their everyday life (hunting and wars)—on the rocks. Long before our era (in the third millenium) the technically perfect painting of North Africa had been developing. It reached its acme in the Fayum portraits (Egypt, I-III centuries A.D.) which was amusing everybody by its realisticity and purity of paints. Even today mineral dyes are the brightest, most durable and pure, e.g. blue aquamarine, green emerald greenery and volkonskoite, bright-red cinnabar, orange orpiment and others.

And now, fresh water! Isn't it also one of the gifts of our Earth? It is certainly a treasure that should be protected with all possible means. In due time, particularly at the time when the industrial activity of people is especially very great, there takes place a contamination of water basins and rivers. The felling of trees brings about the

shallowness of rivers, while the building of some of the reservoirs conversely results in the swamping of comprehensive areas that at one time were fertile lands. The problem of preserving the resources of fresh water and the discovery of the reserves of fresh waters, that could become available by drilling deep boreholes for the water supply of population is at present very acute. The task of the circulation of water in its industrial use with the possibility of using it again has also cropped up.

No minor significance is attributed to mineral waters as a means of curing people of their illnesses. The resources of mineral waters in the Soviet Union are enormous. The exploration of additional reserves of these waters has now acquired a great scope: new hospitals and sanatoriums are being built. Mineral waters receive their useful components—salts of acids, alkali, etc. in the course of their interaction with the rocks in the deeper regions and the leaching of elements from them. Hot springs are formed at the expense of waters that enter from the great depths and are particularly often found within the region of recent volcanic activity. Hot (thermal) waters and vapour of these springs are used for the creation of power stations and the heating of dwellings and hot-houses (Kamchatka, Iceland and others).

We shall discuss only some of the non-

metalliferous mineral resources, though the significance and variety of these mineral formations are by no means inferior to those of metals.

That presents great interest for us is asbestos. The peculiarity of this aqueous silicate of magnesium is its long-prismatic tubular crystals, which can be separated into the thinnest 'stone threads'. The thickness of 'asbestos threads' is sometimes less than 0.0001 millimetre! These threads lead themselves to be woven. Asbestos is a heat-resistant material. Its specific properties of this kind were known as far back as the ancient times.

A very large deposit of asbestos is known to exist in the Urals under the name of Bazhenovskoye. The author happened to be there at one time herself. In the altered ultrabasic rocks the parallel veinlets of aurous mineral of cross-sectional and fibrous structure found their most coherent expression. That was genuine asbestos. It was recovered in the quarry, and the ore was scooped by the voluminous buckets of the excavators and delivered to the preparation plants in trucks, where asbestos was separated from the barren rock. The most long-fibrous varieties of this mineral (the length of fibre exceeding 8 centimetres) are used for the production of materials in connection with the cotton yarn. The yarn goes particularly well with the asbestos thread for the

production of bright, as well as heavy cloths, as, for instance, in making theatre curtains.

Asbestos is added to cotton so that the materials could acquire not only a pleasant lustre, but also no little strength. Asbestos is employed in the production of transmission belts too. The short-fibered variety of asbestos is used in the production of heat-insulating materials. Some of its types have marked acid-resisting properties; they are used for the insulation of underwater cables and the manufacturing of asbestos-cement pipes and plates. Hence, asbestos is a mineral that can be used in many different ways!

Crystals of various minerals of hydrothermal veins: quartz, calcite, and fluorite are found to be highly important for technological purposes. The transparent varieties of these crystals are used in the production of optical instruments.

Calcitic transparent crystals (Iceland spar) possess a marked degree of birefringence. This characteristic feature can very easily be tested. By examining some spot or letter on a piece of paper through a transparent calcitic crystal you will see two spots instead of one. These spots have been created by the two beams that deflect at a certain angle and have a different rate at which the light is transmitted. This property of calcite, i.e. its birefringence, is

made use of in manufacturing special plates for polarizing microscopes.

In quartz crystals, which are also used in the production of optical instruments, it is quite the opposite. What is valued here is the low birefringence of light: they are employed for the manufacturing of quartz wedges that are used for the estimation of the optical properties of minerals. The transparent crystals of quartz serve as an important material for optical lenses.

Special stress should be made on the piezoelectric effect of quartz crystals: under oriented pressure they are found to become electrically charged. The properly preserved crystals of transparent quartz are used for manufacturing the piezo-quartz plates, stabilizers of radio waves and the resonators of depth recorders. In addition to all this, it must be mentioned that quartz glass transmits ultraviolet beams. You must have frequently felt the warmth of the so-called quartz-lamp at the doctor's.

The beautiful varieties of transparent quartz crystals are used as industrial stones for the production of ornaments. Agates are also minerals of the silica group and are used for the stands of precision instruments, the manufacturing of agate mortars, etc. In other words, this is where different properties of the mineral are used, e.g. hardness, transparency, piezoelectric characteristics, and the peculiarities of optical qualities.

The third mineral of this group is fluor spar, or fluorite, which has already a far greater scope of application: in metallurgy it is used for reducing the melt point of the metal, in chemistry it is applied in the production of hydrofluoric acid, in optical industry the colourless and transparent crystals of fluorite, that are rare in nature, are used when optical lenses of special quality are made.

The crystals of technically valuable optical minerals are now developed in special laboratories and plants, where, rectifying Nature itself, people are creating crystals that are quite perfect and large. This kind of technological production of minerals makes it possible to better understand the conditions of their natural formation too.

Such various and customary building materials, as sandstones, granites, tuffs and limestones, are also of great importance.

The combustible fossils (coal, oil, and pyroschists) are important not only for energy purposes, but also for the production of valuable organic compounds that are widely used in manufacturing synthetic materials, or cloths, as well as plastics that in many respects serve to replace metals and steel in technological processes today.

Here we have enumerated only some fields where elements and minerals are applied. The development of technology and particularly power engineering opens up quite

new areas wherein they can be used.

It is absolutely impossible to give a comprehensive account of the way all types of mineral raw materials are employed within the framework of a brief chapter. One thing is clear, however: the mineral raw materials are the basis of industry.

Chapter 18
The Future of Mineral Raw Resources

The intense development of technology results in the depletion of mineral resources. The time when the deficit of a large number of minerals is not far off. Properly this time is already approaching. According to the estimates of R. Smith, over the past thirty years more metals have been extracted from the Earth than during the whole period of their recovery in the world. In USA and West Europe mineral resources are practically being exhausted. This, however, does not include coal. The United States has enough coal for 400 years if gasification will not continue, but on the contrary the figure will be reduced by half. Most of the countries are practically deprived of the resources of oil and gas. The same scientist has produced data that the greater part of oil is in the region of the Persian Gulf and in the USSR. Its resources will meet the needs of people for not more than 80 years. The largest resources of gas

in the Soviet Union are also nearing their exhaustion in the nearest future.

R. Smith lays particular stress on the problems of the deficit of combustible fossils. At present, according to his data, 57 per cent of electric energy is yielded by the combustible fossils (coal, gas, and oil); two are furnished by hydropower stations and less than one is provided by atomic power stations. In his opinion, the past expectations that atomic energy would solve the energy problems have not been realized.

There can be no doubt that the development of hydroelectric stations leads to the silting up of rivers and causes great damage to agricultural lands. The tidal power-stations (based on the function of sea tides) are not possible everywhere, and this construction also has a deteriorating effect on the landscape. The use of underground heat is not boundless either, he thinks. As far as the wind and solar power stations are concerned, they can be used only for domestic purposes. Such are the pessimistic views held by R. Smith on the future of world energy.

The quests of the new sources of energy is a problem of the nearest future. The Earth's combustible fossils should be specially protected. Suffice it to say that Mendeleev himself said that we might as well heat our stoves with banknotes rather than burn oil. Oil is indeed an indispen-

sable and most valuable source for the recovery of various organic synthetic compounds, which at some time in the future can replace metals in many ways. It too is the basis of contemporary chemistry and a possible raw material for the production of synthetic means of nutrition.

Smith's prognostications as regards the future of power supply are pessimistically magnified. Undoubtedly, new technologies of receiving electric energy will be discovered; in particular—the use of heat in the bowels of the Earth, and perhaps also the absolutely new schemes of nuclear reactions on the basis of employing hydrogen for this purpose. However, in the general setting of the problem, Smith is absolutely right and it is with good reason that he raises the alarm. He tries to emphasize the impossibility of restoring the energy mineral resources, the use of which should be extremely careful and which should be regarded as the planet's treasure belonging to all of us.

What is then the situation with the other mineral resources? In the same work by R. Smith it is pointed out that so far only one-third of the industrially developed countries intensely use the mineral products. What will happen after the developing countries get involved in an intense technological activity?

According to what he writes the crisis

of mineral products will be getting ever more acute. There is some reason to assume that in the future what awaits us is a mass involvement of the whole complex of elements of rocks with their mass reworking and a complete utilization of all useful components, and the extraction of all the elements of Mendeleev's periodic table from sea water. The metals will be recovered from lunar rocks (iron, titanium, platinum, nickel, and zirconium). The time of space metallurgy, which will save the Earth from the increasing contamination of the environment is not far off, and it will certainly make it possible to accomplish new technological processes.

But this is something that belongs to the future. For at least the coming decades (or centuries) mineral resources will mainly be recovered from the deposits in the Earth. The content of useful components in the ores will most definitely be on the decrease, and the question concerning the rational means of their use will acquire primary importance.

The bowels of the USSR are still rich in various mineral resources and their depletion will come later than in other countries. However, neither they are inexhaustible.

If the resources of iron and aluminium ores (in conditions of excessive energy expenses) present no special problems, it is

quite opportune to raise the question of preserving some other types of mineral products. This includes mineral resources which are found in few regions of small area, where we can find in particular—tungsten and tin—the indispensable metals in contemporary technology and the ores that are, unfortunately, not widely spread in the deposits.

It is especially important not to waste such a highly deficient metal as tin. In many countries it meets the demands quite satisfactorily at the expense of its recovery from the tins that contained food stuffs.

The value of this kind of secondary and so far waste raw material is very great indeed. The scope signifying the use of tin for such purposes can readily be eliminated from the information available in the press: in the first six months of 1983, three thousand tons of metallic tin were used for the production of 5.5 billion conventional tins containing food. Isn't it the whole deposit?! And if we brought together the tins scattered in all the rubbish throughout the country, we would be able to recover hundreds of thousands of tonnes of the metal in addition to what is recovered from the deposits. An organized form of collecting this valuable secondary product would come in quite handy for tin industry.

With the current progress of technology there will crop up tasks of receiving types

of materials that are yet unknown to us and that are essential for microelectronics, the production of semiconductors, and the materials for the future nuclear technology. At present it is quite impossible to predict these new trends in engineering even for the nearest future.

One of the regular sensations has found its expression in the recent attempt of the Japanese to use ceramics instead of metals in automobile and airplane building industries. Ceramics was the starting point in the technical activity of man, and now, with the depletion of metallic resources there takes place a return to clay—the valuable mineral resources provided by Mother-Earth too.

The mineral products as distinct from the biological ones are not reproducible. Instead of the developed deposit it is not easy to find the new one, particularly nowadays, when the Earth's surface has already been investigated so thoroughly. What can actually and mainly be done in this respect is the discovery of those deposits that do not come out onto surface and are situated in the lower depths. Their explorations make it quite imperative that we should know and study the regularities pertaining to the distribution of mineral resources. Problems of this kind enter into the domains of metallogeny.

Chapter 19
How Ores Are Formed

The knowledge about ores and the features that help to find them among the rocks in the hills have passed on from one generation to another and resulted from people's own experience.

It was the great Greek philosopher Aristotle (384-322 B.C.) himself who created a classification of minerals. Observations of minerals that were formed from hot volcanic waters must have been made by the Romans. Thus, presumably these observations as such had led the Roman architect Vitruvius to the conclusion concerning the emergence of minerals from hot aqueous solutions.

The next page in the history of views on the formation of ores covers the time of the Central Asian culture in Middle Ages. In Central Asia there took place an intense development of the ores of silver, lead, copper, gold and other metals. Guided by the traces of those intense activities of the oldest works the geologists have rediscovered many a deposit today.

The explorers of that far-off period had a remarkable knowledge of ores. They had not been heedless of even a single outcrop of ore bodies. I saw the whole zones of ditches and narrow holes in the red ferrigenous rocks of the type I had frequently

seen in Central Asia. It was with the enthusiasm of a pioneer that I had investigated the ore-bearing bed among the sandstones in one of the ore regions of Fergana, where actually after every ten steps or so I would come across a narrow chink or hole that had passed along the lead-zinc ores. Even then it was possible to see the remains of ores in the barren rocks, or dumps, that had been ejected from the workings which had the form of crescents that surrounded the openings of the entrances leading to the ancient parts of the mines that had been dug out.

And what remarkably large mines I happened to see on a number of occasions among the limestones in that same Asia. This is where I saw complex tubular bodies with geniculate curves, and sometimes having the form of a spiral too. It was not an easy job to penetrate into the workings along those adits. At some places it was even impossible. How then did the ancients manage to work there?

The ore was brought out onto the surface in sacks. There were clay lamps and primitive hammers inside the workings. It was really a problem to extract gold, silver and other metals from the bowels of the Earth so that those in power could become more powerful. It might not be too far-fetched to say that the work was done by the slaves, and in the narrow apertures the

labour of children might have been used.

We would get into the spacious halls with lofty arches and steep walls. Calcitic stalactites from the top and the stalagmites from the floor merged into whimsical columns.

The sounds of that epoch are now dead. What we can hear now in the caves of the ancient mines is the rustle of bats. Our voices are hollowly thrown back to us under the high vaults. It is with gratification that we think of our remote ancestors from whom we have inherited those valuable treasures!

What astounds us is not only the exploratory art of the ancient miners, but also the theoretical conclusions concerning the origin of ores at which the scientists of that period used to arrive. Thus, the famous Tadzhik scholar Biruni (the ninth century) observing the minutest droplets of a liquid in the crystals of minerals made an absolutely correct inference as regards their sedimentation from the aqueous solutions. This was nearly one thousand years before the concept of the origin of minerals and ores was formulated.

His contemporary, the renowned scientist, physician and philosopher of Central Asia Avicenna (Abu Ali Ibn Sina) was interested in minerals primarily for the medicinal purposes as well as the source of

receiving various chemical compounds. At the same time, however, he had a sound knowledge of minerals and compiled their classification, distinguishing among them stones, fusible bodies (metals), sulphuric, combustible substances and salts.

Now let us discuss quite a different part of the world—the Central Europe. The development of ores has been in progress here since the fifth century. Many thousands of ore veins, from which tin and silver, as well as other metals were most intensely recovered, had already been known.

The experience of the miners in Saxony was generalized by the already previously mentioned eminent scholar and physician G. Bauer (1494-1555) who received the sobriquet of Agricola. In the same way as physicians of the ancient times he was interested in minerals mainly because of their curative properties. But he got so deeply concerned with mineralogy that he became a prominent specialist in this field and acquired no minor experience in ore-mining production. Out of his numerous books the one that is more widely known is *De Re Metallica*. The illustrations contained in the book show dwarf-miners at work. We can thus trace various stages of their operations, beginning with the explorations with a rod, which, as was considered, helped to find the ore veins, and served equally well for the purposes of output,

sorting of ores, and their melting in special kind of furnaces.

Agricola suggested very interesting ideas about the origin of ores. He, too, was trying to solve the problem concerning ore formation, why they are found in fissures and compose bright ore veins. He came to the same conclusion as Biruni that vein minerals were deposited from aqueous solutions and called them juices. According to Agricola, juices were no more than heated waters which were somehow impregnated with metals which were solved by them from rocks, penetrating through them; what served as evidence of the leaching and redeposition of metals included his observations of the chrysocolla on copper coins. He adduced examples of the current deposition of the globules of calcium carbonate in hot mineral springs, basing his assumptions on precise geological observations.

The ideas that had much in common with those expressed by Agricola were elaborated by M. Lomonosov, who happened to be at one time in Saxonian mines himself, and must have been under no minor influence of miners and natural scientists working there. But with Lomonosov we already find concepts that also pertain to the impact of deep-seated processes upon ore formation and, in particular, on the tectonic movements, which find their expression in earthquakes. These ideas were

expounded by him in his work *On the Origination of Metals as a Result of Earthquakes*. He saw the factors conditioning the heating of waters of ore-forming solutions in underground coal fires or the burning of sulphur under the Earth.

What is extremely interesting is that the initial scientific concepts of outstanding scientists who worked on their own were by no means remote from the ideas about ore formation that belong to our present age. Later, however, with the further development of scientific schools, the differentiation of scientific concepts was becoming ever greater and there appeared proponents of various and in some cases totally incompatible hypotheses. A particularly marked outburst of theoretical discussions took place at the end of the eighteenth and the beginning of the nineteenth centuries in Saxony itself, which had become the centre of scientific geological thought after the Freiberg Mining Academy was founded.

This period was characterized by the well-known discussion between the plutonists and the neptunists. The former were elaborating the idea about the origin of ores, as well as rocks (basalt, granite and others) from the magmatic melts. They were the followers of the Scottish naturalist J. Hutten. This hypothesis of the deep-seated source of matter received the name

of the god of underground kingdom Pluto.

Those who adhered to the opposite theory, the neptunists, were called so in honour of the god of the seas Neptune. They proceeded from the assumptions that rocks, as well as ores, emerged from the waters of the World Ocean, which had covered the whole surface of the Earth during the Flood. Aqueous or sedimentary origin was also attributed to granites, basalts and other rocks, which the plutonists considered to be magmatic. The one who initiated this trend was the celebrated professor of the Freiberg Mining Academy A. Werner. An exceptionally high authority of this prominent scientist and teacher promoted the consolidation of neptunistic ideas for many ensuing decades. Goethe, who was an ardent supporter of Werner, shared these ideas too.

Today, assessing these ideas in terms of their historical value, we can see that alongside the misconceptions (sedimentary origin of granites and basalts, mystical belief in the Biblical Flood), Werner's ideas had also a grain of the truth. First and foremost this can be said of the question concerning the origin of ores. Observations of the veins of Saxonic deposits have revealed that the minerals in them are situated in the form of layers or crusts on the walls of fissures, alternating in succession. Some of them give rise to crystals, growng towards the

centre of the veined fissure, that were presumably formed in the voids. These observations have adequately testified to the fact that veins had actually been formed from aqueous solutions. In compliance with his own concept Werner erroneously considered the World Ocean, and not the Earth, to be the source of these solutions.

The later period saw a synthesis of the ideas adhered to by plutonists and neptunists in the theory of the origin of ores from hot aqueous solutions, but already not of the surface variety, as was regarded by Werner, but the deep-seated ones, ascending from the solidifying magmatic bodies in the deeper regions. In this theory, which is usually associated with the name of the French scientist L. Elie de Beaumont there seemed to have taken place a synthesis of the opposite views of the plutonist J. Hutton and the neptunist A. Werner.

In his conclusions about the deposition of minerals of ore veins from hot aqueous solutions, Beaumont proceeded primarily from the data concerning the minerals that emerge from gases and hot waters during volcanic eruptions. In Russia similar ideas long before Beaumont have been expounded by the professor of St. Petersburg Mining Corps D. Sokolov.

However, many questions pertaining to ore formation continued to be discussed even later. Thus, at the end of the nine-

teenth century the attention was again focused on the deliberations as regards the source of ore matter: where do the metals come from; do they enter the solutions from the rocks along which waters had been circulating, as was the point of view shared by Agricola and Lomonosov, or are they issued from the magmatic bodies, as was asserted by Beaumont, or, lastly, from still greater subcrustal depths. Or, do they originate in the heavy shell, the so-called barysphere, which in our understanding of the term, is correlated with the mantle. These versions of ore formation are in the main discussed even today.

As we know now, ores can have different origin. Some of them are sedimented in water basins—seas, oceans and lakes, and form part of sedimentary masses; others are formed from magmas or aqueous hot solutions of magmatic or deep-seated origin. Still others emerge during the change (metamorphism) of the earlier formed rocks of sedimentary or magmatic types.

Sedimentary rocks are connected with a very large number of mineral resources. First and foremost the rocks themselves serve as the object of development for a host of various purposes. You can readily imagine the significance of sands and clays for the production of cement, and that of limestones for the manufacturing of lime. These materials are indispensable for the

building of houses, dams, and hydroelectric stations. Sandstones as well as limestones, or the marbles that are formed during their recrystallization, are used for facing the walls. Besides, marble is a priceless material for the sculptors.

Sedimentary masses are connected with the deposits of such mineral resources as peat and coal, which have been formed from the remains of plants and trees of the remote geological past of the Earth. The organic compounds have also yielded such a highly important product for our current activity as oil.

But how did it originate? The theory that oil was formed from organic remains is now preponderant. A significant role in the accumulation of carbohydrates of oil and gas was played by the decomposition of plankton—the tiniest floating plant and animal organisms that form concentrations in the sediments after they are perished. The gaseous and liquid products of this kind of decompositions—oil and gas—are transported through rock masses and accumulate in the more porous of them under the cover of compact and less penetrable ones. In most cases these light products of organic origin rise into the arches of anticlinal folds.

Sedimentary origin is also shared by the deposits of potash, sodic and magnesium salts, which were deposited from water

in the lagoons as a result of evaporation.

I happened to see very interesting developments of salt in India. They had the form of square lots in the lake, that were separated by dams. The technology of the process of recovering salt here is not complicated at all: the principal driving force is the Sun. Salt is sedimented in the course of the evaporation of water in the form of wonderful crystals on the bottom of the water bodies. A framework of some whimsical construction made of wire, when submerged for twenty-four hours, is recovered by the workers knee-deep in the brine to fascinate the enchanted spectators with its sparkling saline crystals that look like a toy castle.

These saline lakes are presumably not the remains of a sea, but have emerged as a result of the leaching of sodic salts from the rocks. A typical example of sea evaporation is the Kara-Bogaz-Gol Bay, where layers of salts of various composition are periodically deposited.

But it is not only the non-metalliferous mineral resources that are formed by means of sedimentation: the latter process also gives rise to concentrations of iron ores. You can become immediate witness of some of them. Thus, I happened to see rounded segregations of brown iron ore with the diameter of several centimetres, that were deposited on a barbed wire from a defensive

line near the trenches of World War II not far away from Leningrad. The rate at which these iron ores (concretions) were growing was determined accurately enough. It was up to one centimetre a year.

The sedimentations of brown iron ores on the bottom of the lakes, the so-called marsh ores, have been known in Russia for a very long time. They were the ores that were delivered specially for the plant that was founded by Peter the Great near Petrozavodsk.

The accumulation of iron and manganese with an admixture of other metals in the nodules takes place on the ocean floor. The reserves of these oceanic separations of iron are enormous, though it is by no means easy to recover these ores from the depths of four and more kilometres. The geologists study the composition of these ores. In the solution of the problem pertaining to their development the oceanologists, geologists, chemists and economists should all participate. The task is really difficult but it is worth trying: the ocean floor contains priceless treasures of metals that can serve mankind for many centuries to come.

What we have been discussing here is the contemporary sedimentation of iron ores. But did such processes take place before? There is every reason to believe that in the past, too, iron ores in sedimentary rocks were formed likewise in

sea and lacustrine basins. It was precisely in this manner that the largest deposit of ferruginous quartzites of the type of Krivoi Rog and Kursk magnetic anomaly had emerged.

It is certainly worth mentioning that in other countries and in other continents ores of this kind were deposited mainly in the early stages of the Earth's development. It was the epoch of the total enrichment of the earth's crust with sedimentary iron ores. This process must have been influenced by the characteristic features pertinent to the composition of the atmosphere and the hydrosphere in the early stage in the history of the Earth which resulted in the leaching of iron from the rocks.

In that very ancient period of intense and comprehensive manifestation of volcanism iron was brought into the basins of sedimentation by river water, volcanic gases, and hot solutions rich in strong solvents.

Sedimentary origin is also typical of other metals, as, for instance, copper. They include the largest deposits of cuprous sandstones of Udokan and Dzhezkazgan. These deposits were formed during the washout of the cupriferous volcanic rocks and ancient copper deposits, and the removal of metal into water bodies, where cupriferous fragments of rocks and ores brought by the solution of copper were sedimented. In

the later period these ores were metamorphosed, and in the beds of cuprous sandstones there emerged intersecting veinlets from the copper minerals redeposited in the fissures.

I can most definitely say that sulphide ores (kies) can sometimes actually emerge from volcanic gases. I was fortunate to see these ores formed from the solutions saturated with gases and that came up from the deeper parts of the volcanic system; this was in the South Kurils.

The Mendeleev volcano on the southernmost island of Kunashir of the Grand Kuril ridge has already been slumbering for quite some time, and yet its depths are remarkable for active processes. On its slope and onto the surface gaseous jets of sulphurous compounds are burst out, and it is right here where native sulphur is deposited, while a little deeper we can find sulphide pyritic ores—precisely those which are the subject of a heated discussion.

Across the brushwood of low and thin-stemmed bamboo the neglected old sinuous path descending along the slope brought us to what used to be a sulphuric mine. The rocks—lavas and tuffs—are clarified here and are markedly distinguished in the form of a yellowish-white spot against the dark background of invariable andesites. And over this spot we see the thick sulphurous evaporations that hang down in the shape

of white globular figures. They originate in the numerous hot springs situated below. As soon as you drop a blade of grass into this boiling well, you will see it all covered with sparkling little bits of sulphur.

On the surface the sulphurous gases are oxidized and along the mountain slope there comes down the water that bears in itself sulphuric acid. These oxidized waters interact with lavas, decompose them and leach the iron, which is exactly what accounts for the clarification of rocks. Meanwhile the compounds of iron that are dissolved in waters run down and become sedimented in the sinters of brown aqueous iron oxides. In their turn the interaction of these oxides with sulphurous gases leads to the sedimentation of black sooty sulphides of iron. These are what we call the 'pyrites', which in millions of years will have the appearance of sparkling pyritic brass-yellow sulphide ores with which we are so well acquainted in the regions of ancient volcanism.

But look! It occurs that pyrite can also be formed in our sulphurous (solfataric) field. Right under our feet we see golden fragments of crocks. They are the smithereens of a broken piece of pig iron, which have been wholly replaced by pyrite (FeS_2) under activity of sulphurous solutions. The formation of this kind of pyrite did not re-

quire millions of years: the miraculous transformation took place only within the period of one decade after the sulphur mine stopped functioning.

In our solfataric field we have the formation of not only sulphides of iron. The geologists, when washing the heavy concentrate from the alluviations of a small river in their boat, used to discover very bright crimson little crystals of cinnabar, spectral analysis helps to find copper and zinc in ores too.

With unabated interest we watched this contemporary natural laboratory, where there occur processes of mineral formation connected with the activity of gas and aqueous hot springs on the slope of a dormant but not yet extinct volcano.

We went down by the River Kislyi Klyuch (acid spring). The water in it is really sour and the suspension of colloidal sulphur had given it a milk-white colour. Colloidal sulphur falls out under the neutralization of acid sulphurous water by the alkaline ones that come from the rocks themselves. Above the warm stream there hangs a whitish smoke of evaporations, and in this natural hot house we can find blackberries of very large size. What we see here is a fabulous land flowing with milk and honey.

Ores are also formed in the volcanic lakes that exist today, and which the metal-

bearing hot jets enter from the depths of the dormant volcano.

And now Kamchatka! Every geologist dreams of visiting it at least once. What has been the cynosure over the past few years is the renowned metalliferous Uzon Caldera.

A caldera can be defined as a rounded oval of 'subsidence', formed during the sinking of the upper part of a volcano, after a great deal of matter has been ejected from its deeper regions and a void was formed. It is common knowledge that nature does not endure vacuum, and so the masses of rock overlying it had subsided. Within the sink of this kind of subsidence an emerald-green little lake was formed on the bottom of which hot volcanic springs are bubbling most intensely.

Sometimes orange films can be seen on the surface of the lake, before they were taken for the ferruginous varieties. The researchers of the Institute of Volcanology, however, proved that in reality what gave the films their colour was not the oxides of iron, but the sulphurous compounds of arsenic—the bright orange realgar and the golden-yellow orpiment. Then on the bottom they discovered a layer of ore-bearing sediments with the same arsenious minerals, as well as with the sulphurous compound of antimony—antimonite. A member of the Institute of Volcanology S. Glavat-

skikh proudly showed us large 'druses' of wonderful acicular steel-grey crystals of antimonial lustre. She took them out after diving into the hot waters to the small holes, or apertures, from which the metal-bearing waters were flowing out in a strong stream.

The Uzon Caldera example substantiates the current idea about the primarily sedimentary formation of some of the bedded deposits of antimonial ores, which, in particular, are known in Eastern Europe.

Over the past few years much has been said about the sedimentary formation of a large number of lead and zinc deposits of ancient age (approx. 1.6-1.8 billion years). This type includes the bedded ore bodies of Australia and Canada. The sedimentary origin of ores finds its expression in the alternation of thin interlayers of sulphides of lead, zinc, and clay rocks. These 'little layers' of various composition are crumpled into small complex folds.

The deposition of lead and zinc semi-liquid (iron-like) ores is found on the sea floor. Lead and zinc fall out in the form of sulphurous compounds from concentrated solutions (brines), that come along the fissures from the depths of the sea (mantle). Formations of this kind are known to exist on the floor of the Red Sea and in the eastern part of the Pacific Ocean.

Highly specific are the sediments of sulphurous compounds of lead and zinc in the pipes of the oil boreholes in the region of the Caspian Sea. The metals here were also delivered from the depths in the composition of waters of oil-bearing basin. In this case the source from where the metals come can be not too deep. It is most probable that it is situated in the outer part of the earth's crust.

The volcanic rocks are sometimes connected with such metals as gold and silver. Such are the gold and silver deposits of North America and some of the ore regions in the East of the USSR. The auriferous veins are often situated on the vent funnels. The latter also comprise some of the largest copper and copper-molybdenum deposits of the so-called porphyry ores, containing inclusions and veinlets of ore minerals in volcanic rocks.

The opinion has recently been expressed that some of the antimonial and tungsten deposits with scheelite ($CaWO_4$) of the bedded form were also formed by means of sedimentation from the solutions of volcanic origin. In other words, it transpires that sedimentary masses serve as an inexhaustible source of various useful minerals.

The deposits connected with the deep-seated source of an ore substance, with magmas or solutions that come from the mantle, are formed in the course of tectonic move-

ments at the time of folding or during the development of faults.

The association with magma leaves us no doubt for ore minerals, which give rise to the dispersed inclusions or veinlets (platinum) in ultrabasic rocks. In some cases ore minerals are so rich that they become rock-forming, i.e. an indispensable component of a rock that was crystallized from a melt (chromite).

Neither can there be any doubt as regards the connection with the ultrabasic rocks of the copper and nickel ores, which form in these rocks interlayers, lenses, and sometimes also the veins with the segregation of minerals in the fissures intersecting the rock. This can be illustrated by the deposits of the region of Pechenga in the Kola Peninsula and Norilsk in the Krasnoyarsk region.

Tubular bodies of ultrabasic diamond-bearing rocks, or kimberlites, may be said to be really peculiar. They intruded from the mantle out of its great depths (250 kilometres). It is considered that the rocks were formed at the time of explosion in the deeper regions, and it was under a markedly great pressure and explosions that diamonds were formed. We can find diatremes of this kind in Africa, and in the past decades they have also been discovered in Yakutia (USSR).

Basic rocks are connected with the deposits of iron, titanium, and iron-copper-

and-vanadium ores. The magmatic deposits of this group are widely spread in the Urals.

Magmas can also be associated with the deposits that were formed not only in the depth, but that have appeared during the volcanic eruptions on the surface. This group includes tin deposits with the concretions of tin stone in acid lavas and some of the copper- and sulphuric-pyrite deposits, as well as the mass concentrations of the so-called pyrite, sulphide ores in volcanic rocks. The origin of these deposits is being discussed at present: some geologists think that the ores had emerged from the solutions that enter from the depths; others adhere to the opinion that the direct origin of the ores was the outflow of lavas. Presumably, both of these factors exist in nature, though it is difficult to distinguish them, particularly if the ores have been recrystallized and altered.

Tin and tungsten are usually associated with granites. Quartz veins with tin stone and wolframite in the granites and in their closest environment are widely known. Tin is sometimes found in the volcanic rocks. Thus, in North America tin manifestations are comprehensively developed within the belt of acid (enriched with silica) volcanic rocks, which extends over thousands of kilometres across the states of Nevada, New Mexico and along the territory of Mexico itself.

This belt is known for hundreds of small deposits, where tin stone (cassiterite) gives rise to sparkling brown nodules with concentric rings of different colour: black, brown, and cream, that have emerged from the clots of colloidal solutions. Here, too, we can find veins containing cassiterite. It is absolutely evident that tin was delivered by no other agents than the acid lavas. Sometimes, however, it is possible to see direct transitions from the lavas that had flown out onto the surface to crystalline rocks that enter into the composition of volcanic necks. These rocks are already approaching the granites, and we can also see separation of cassiterites in them.

I happened to come across stanniferous granites in which the crystals of cassiterite together with other minerals (quartz and feldspar) grew in the form of druses on the walls of barren rocks. These segregations must have appeared in place of the gas bubbles that had saturating the magmas, i.e. here, too, we have some evidence as regards the direct bond existing between the metals and the magmatic rocks.

However, stanniferous veins intersecting the granites or situated beyond their limits are the ones that are most widely spread. But in these cases, too, we can often manage to prove that ores are directly associated with granites: the closer they are to granite, the higher we find the temperature

of the ore veins, which means that the stanniferous solutions have been propagated from the granites.

Thus, in a large number of cases the source of metals in ore veins is the magmatic rocks formed from the magma that was supplied either directly from the subcrustal depths, or that has emerged as a result of the melting of the earth's crust.

What then is the role of enclosing rocks in the formation of metals? Was the great Lomonosov wrong when he stated that the solutions, penetrating through the Earth, extract its metals, leaching them out of rocks?

Within the earth's crust elements are said to be in a state of circulation. This finds its expression in that their initial supply goes together with the volcanic rocks and there takes place a regrouping conditioned by metamorphism, and the 'mobilization' under the activity of later magmatic bodies, or during the penetration of the solutions of deep-seated origin.

Chapter 20
The Science of Metallogeny

The role of the analysis of geological conditions for the exploration of ores was pointed out by Lomonosov, who found it quite important to distinguish between those places that could contain ores from the

ones that were not suitable for that purpose. 'Now let us set on a journey throughout our country and see how everything is situated separating the territories that can yield ores from those that cannot; then in the places that are favourable for the formation of ores let us look for the features that could reliably indicate the very places where ores could be found. After that it will be our task to look for metals, gold, silver and other things so that we could get down to splendid stones, marble, slate and even to emeralds, stones like rubies and sapphires, and the diamonds. Our journey will not be tiresome. Though we shall not find treasures everywhere, we shall at least see the minerals that could be made use of in production and thus bring us no minor profits...

Metals and minerals are not merely a gift of nature. They require elaborate survey and no less strenuous labour to be recovered in their placers.'

Lomonosov's prediction came true: metals and 'splendid stones' have been discovered in this country. The quest is in progress with the indefatigable geologists following the recommendations given by Lomonosov years and years ago!

What helps them in their exploration today is the science of metallogeny.

The task of metallogeny is to bring to light the regularities pertinent to the distribution of deposits in the earth's crust. Min-

eral resources are not equally propagated. Some of them are found in regions that are by no means large in area (e.g. tin). The quest of these places and deposits without having a clear-cut itinerary for the survey and a scientific prognosis is exactly the same as looking for a needle in the haystack. The present-day explorations are to a great extent facilitated by the fact that we can be guided by certain rules.

However, this was the case long ago, when our gifted ancestors could find ore deposits, directed in their exploits by observations and practical experience. As early as their time they had already pointed out that the deposits of one and the same mineral resource were often found to be situated close to each other. The Russian miners had formulated this conclusion in their own way: ore is near the place you have found it!

The attention has long been drawn to the fact that a large number of deposits are situated along some particular lines. The little circles indicating deposits on a map look very much the same as the threaded beads, while the threads themselves represent the faults, fissures, in the direction of which the ores are most likely to occur.

The linear arrangement of deposits in particular zones was pointed out by Lomonosov himself. Thus, he said that the copper deposits of Kamchatka and Japan belonged 'to one and the same ridge, that found

its expression only in the islands that came out onto the surface of the water'. Nowadays we know that it is precisely there that the interior zone of the Pacific ore belt is situated.

Very interesting ideas concerning the location of gold placers in the extended planetary belts were expressed in the middle of the nineteenth century by the Russian mining engineer, I. Poletika. He said that the gold-bearing zones were stretching from the Urals across Siberia, on the one hand, to the South, towards Java and Sumatra, and, on the other hand—in the northern direction and extended along the American coast of the Pacific Ocean. And it is these conclusions that form the basis for the future concepts as regards the great Pacific ore belt.

It is noteworthy that Russia was exactly the country where so much attention was paid to the regularities in the distribution of mineral resources and the discovery of ore-bearing belts and zones in the Urals, Altai, and later in the Transbaikal and in the east of the country. And this is by no means accidental: the knowledge was derived from the experience in studying the vast and assorted territory of the country. They were of dire necessity for the quests of new treasures in ore. And it was again Lomonosov who called on his countrymen not to slacken prognostications. Many of them

made by the geologists were later substantiated by highly important discoveries.

The experience gained by the geologists doing the practical work was generalized in the science of metallogeny, the scientific study of the general regularities of the distribution of deposits. This branch of science is naturally connected with other fields of geological knowledge and makes use of its data to determine the influence of various factors conditioning the arrangement of mineral resources: the composition of sedimentary and igneous rocks, the tectonic structures, and now also the deep-seated structure of the Earth. It is precisely the overall analysis of the combination of diverse geological conditions that helps us to understand why a certain deposit of mineral resources is situated precisely in the given belt, where by analogy with it we can also find other deposits of the same type.

An important role in establishing the general regularities in the way mineral resources are distributed in time and space was played by one of the most prominent Soviet geologists Yu. Bilibin. He was the first to scientifically substantiate the regularities that had been known to geologists. He proceeded from the conclusions drawn by the tectonists, and primary from those of the German scholar H. Stille concerning the factors conditioning the development of mobile zones, or the geosynclines. Following

those principles, Bilibin determined that ore deposits also undergo regular alternations in the course of the progress of geosynclinal zones.

In the early stage, when there takes place the formation of deep faults that penetrate into the bowels of the Earth, the basic lavas, or basalts, enclosing copper- and pyrite bedded deposits, start overflowing. Along the faults that are deeply rooted in the interior parts of the Earth, there simultaneously or a little time later occurs the intrusion of ultrabasic and basic magmas. The massifs of igneous rocks that emerged from them are connected with the magmatitic deposits of chrome and platinum (in ultrabasic rocks), titanium, copper, vanadium, and iron (in basic rocks). Examples of such ore deposits can be found in the so-called green-stone belt of the Urals. According to Bilibin, these formations reflect the early stage in the growth of geosynclines.

This is followed by the accumulation of fragmental rocks, their submersion into depths with the subsequent appearance of folding accompanied by the intrusion of more acid masses of granitoids. Bilibin termed it the middle stage in the development of geosynclines. As far as granitoids are concerned, they are associated with other metals and different kinds of deposits, or those of the ferruginous or copper types situated in the skarn deposits at the contact of gran-

ite massifs, while in the granites themselves we find the tungsten and stanniferous land masses in the form of quartz veins, as well as various deposits of rare metals in pegmatitic veins.

The third, or the later stage in the development of geosynclines, coincides with the post-folding period of the formation of faults, which is characterized by the origin and growth of minor intrusive bodies with their own 'set' of mineral deposits. This is the time when the composition of ores is already more diversified, and here we can find gold and silver, antimony and mercury ores, and also lead and zinc ores.

These general regularities were adopted by Bilibin to designate on the maps the zones of the development of magmatic rocks and ores of various stages. The metallogenic maps correlated according to this principle make it possible to prognosticate the discovery of complexes of deposits characteristic of each stage and every type of metallogenic zones, which can be either chrome-bearing, auriferous, stanniferous, or of some other kinds. The fact that we know their features helps us in our exploration of ores.

One of the methods of analyzing the regularities pertaining to the distribution of deposits is the compilation of metallogenic maps, on which the basic geological features of the region are reflected, i.e. the age

and composition of sedimentary and magmatic rocks, the main tectonic forms (anticlines, synclines and faults), and which definitely show the ore deposits themselves expressed by symbols signifying their composition and genetic type. The analysis of these maps can be found not only useful for directing the quest of new deposits; it also provides the material for the discovery of the general regularities in the distribution of metals and their diverse genetic types. Each metal has its own 'habits', its favourite rocks, in which it is found most often, as well as particular structural elements that are more propitious for the formation of deposits.

The complex circulation of substances in the earth's crust can be exemplified by iron and manganese. These metals, and especially iron, are of pallial origin, and have been brought into the earth's crust by the basalts, intrusive basic and ultrabasic rocks. Further, however, they undergo complex transformations in the process of superficial alterations of rocks and sedimentation. When the igneous rocks are being destroyed, these metals are transferred into solutions and are evacuated into water basins, where they become concentrated in sedimentary layers. We have already discussed 'the great accumulation of iron' in basins of the Precambrian period with formation of enormously large deposits of ferruginous quartzites.

What concentrates in the sediments initially includes carbonates and aqueous oxides of metals (for iron it is limonites). During the subsidence of the layers in conditions of high temperatures there emerge magnetitic and hematitic ferruginous quartzites, while at still greater depths we can find the formation of the silicates of metamorphic masses. For manganese it is the so-called gondites the rocks that contain manganese garnet known in India.

The metamorphic masses deposited in the depth are rich in iron and manganese, and particularly enclosing ore deposits of these metals, become subjected to the impact of granitic magmas that emerge during the melting of the deeper parts of the earth's crust. The granitic mass is then enriched with these metals.

The hot ore-bearing solutions also adopt iron and manganese from the deep-seated masses, which on a higher level give rise to hydrothermal deposits. Iron and manganese, that play no little role in a large number of ores were presumably adopted by the solutions from the roads while they were in the process of movement.

The question concerning the role of adopting metals from the enclosing rocks on the border separating the nineteenth and twentieth centuries was the subject of very heated discussions. 'The metals entered the solutions from the rocks', was what the pro-

ponents of the so-called lateral-secretion hypothesis were wont to say. 'No, their supply came from the depths' was the objection made by their opponents. At present we know that the two types of sources of an ore substance share considerable importance. This can be more readily apprehended if other highly significant ore elements were commented on here.

There are features that unambiguously reveal the supply of gold coming from the magmatic, mainly basic, rocks, in particular during the volcanic eruptions. What becomes of gold after that? The auriferous veins are destroyed, the gold, as a heavy mineral, is accumulated in the loose deposits (sometimes in the sands of sea beaches), and thus the sediments are enriched with this metal.

In the course of further geological processes, when the gold-bearing mass subsides to a greater depth into the region already characterized by the prevalence of high temperatures (over 300 degrees) and where the pressure is increased, there takes place a regrouping of substances: the dissolution of some of the minerals, the crystallization of others, and the emergence of gold and quartz veinlets of metamorphic origin. These veinlets can later be crumpled together with the sediments and form a series of irregular lenticular bodies. And in those places where these auriferous altered rocks are

intersected by the younger magmatic bodies, e.g. granites and diorites, there appear new and much larger gold-ore veins or the auriferous zones of impregnated ores. At the expense of the destruction of these ores we have the formation of placers, and gold is again supplied into the cycle of sedimentary accumulation.

Thus, there takes place the circulation of gold, which covers different cycles of geological processes, such as the initial delivery with volcanic rocks, sedimentation in basins, regrouping under metamorphism, 'mobilization' during the activity of later magmatic bodies or in of the case the penetration of solutions of abyssal origin.

Now, let us have a closer look at the circulation in the earth's crust of another frequently occurring metal—copper. Copper, as a metal, that yields soluble compounds, is the most illustrative example of migration and recurrent circulation in the earth's crust.

Copper ores can be of various origin, though in most cases they are connected with the deep-seated rocks. We can see this apparent bond with the rocks of the basic composition in the Precambrian lavas of Lake Superior (USA), where the voids of volcanic rocks are filled with copper minerals, including native copper. It is clear then that the source of this mineral was the same magma, from which lavas were formed at the time of the eruption.

In Chile the basic volcanic rocks on the seashore are in some places enriched with ore impregnations of copper sulphides, with the richer beds being developed even further. But in this field we can also find other types of deposits—sulphide veins and the deposits at the contacts with the granitic masses that intersect these lavas. Evidently, during their formation, too, there took place a 'mobilization' (adoption) of metal when the new magmatic melts were supplied, its evacuation by the solutions and the redeposition in the form later enriched ores.

The migration of copper is also influenced by the surface agents. There here the ore deposits come out onto the Earth's surface after the washout of rock masses, the copper minerals undergo the process of dissolution. The compounds of copper are evacuated by the river waters in solutions, and are then sedimented in the basins together with the fragmental material. This is how cuprous sandstones and schists originate. Under a high concentration of copper in the water basins Mansfeld cuprous schists were formed (GDR). The remains of numerous skeletons of fishes that were replaced by sulphides and buried in the cuprous layers may well illustrate the deteriorating effect of high concentrations of metals in the water basins for any life activity.

It is also tin that becomes involved in the circulation of matter. As distinct from copper and gold, which are often connected with the basic rocks, the primary ores associate mainly with the acid varieties of rock, and principally with granites. Tin is not infrequently concentrated in quartz veins and veinlets together with tungsten and nonferrous metals that give rise to sulphides. In some regions the mineralization of tin has taken place on a number of occasions. Thus, in Asia Minor, tin must have been delivered from the depths of the earth's crust by the granites of different ages, viz. those belonging to the Carbonaceous, Triassic, Jurassic, Late Cretaceous, or Tertiary periods. Within this interval of time (over 250 million years) the migration of tin is assumed to have been often in correlation with sedimentary processes marked by an intermediate accumulation of cassiterites in the placers of either terrestrial or marine varieties (on the shelves). At every single new outburst of magmatic activity there occurred a 'mobilization' of the metal from sedimentary rocks, their enrichment with granitic melts, and the later ore-bearing solutions, which were exactly what accounted for the formation of quartz stanniferous veins of various epochs.

A still more lengthy circulation of tin found its expression in the Bolivian tin-ore province. There is some reason to believe

that the primary tin in the form of cassiterite was enclosed in the Precambrian (Proterozoic) pegmatites, coarse-crystalline rocks connected with the granites. In the later period (Devonian age) placers were formed in the sedimentary masses of sandstones. And already after a prolonged break in time new movements of the earth's crust in the Triassic, Jurassic and then in the Tertiary time had brought about the formation of very rich veined deposits.

In exactly the same way one could explain the recurrent manifestations of the mineralization of other metals, which led to the enhancement of the geochemical and metallogenic heterogeneity of the earth's crust.

It would be most interesting to trace this kind of circulation of matter in the field of ancient folded structures. It is precisely they that enclose in their depths the metals that were supplied in the first and more productive stages in ore formation, when the mantle had not yet been depleted by ore elements and enormous concentrations of ores emerged.

The early periods of the Earth's history were characterized by the formation of still poorly differentiated basaltic rocks with the dispersed and on the whole not very high content of ore material, though under the impact of later melts and solutions there took place the regrouping and displacement of substances including ores.

The main accumulations of the Earth's ores appeared in the early stages of its development, i.e. in the Archean and Proterozoic periods. Then the still 'young' mantle was not depleted: ore elements had not been extracted from it as was the case later; and yet it was already rather differentiated, which was exactly what conditioned the incursion of ore-bearing melts into the earth's crust.

As far back as 3.8 billion years ago there began and continued until one billion years prior to the present moment the formation of generally developing ferruginous quartzites. Apparently, the formation of iron ores of this type was accompanied by various processes including the surface ones, i.e. the removal into the basins of a large amount of iron, relieved during the decomposition of the basic volcanic rocks in the humid warm atmosphere of the early stages in the development of the Earth, and the deep-seated supplies of metal with the lavas in the zones of deep faults. The formation of iron ores was also influenced by the chemism of the atmosphere of those days, in particular the already fairly high content of oxygen, which resulted in the emergence of the oxidized form of iron (hematite) together with the protoxide form. Hence, the ancient period may well be referred to as the specific epoch of the accumulation of iron. At the same time, however, there was

also taking place the 'preparation' for the formation of concentrations of other metals.

The formation of the largest fractures in the crust that date back to the period of 2-1.8 billion years ago were accompanied by the intrusion of great magmatic masses from the deep regions to the surface, in which various rocks took part. They included ultrabasic rocks with chromium and platinum as well as the acid ones containing tin. It was a period marked by the enormous fracturing of the earth's crust.

In the relatively early stages of the development of the Earth the earth's crust was divided into two geochemical types: the acid variety, or sialic (basically at the place of gneissose granite domes with an acid crust) and the main type (femic) situated in the troughs, composed of basalts, with the change of which there emerged the greenstone belts. The territories of the first type were even later characterized by the development of granites and their related rare-metallic mineralization, while the territories of the other type were noted for the further progress of basic rocks, accompanied by the deposits of iron, copper, and gold. The lead and zinc deposits were formed in the Proterozoic troughs filled with black clay rocks, that are rich in organic compounds, which were presumably the ones that exerted their influence on the sedimentation of ores.

The ore provinces of sialic nature include regions characterized by the development of the ancient granitoids of Africa, South and, partly, North America, and Western Australia. What is typical of them is the frequent intrusion of granites that bring forth the mineralization of the same complexes of metals. For instance, rare-metallic mineralization had a common feature shared by Pre-Cambrian granitic massifs and pegmatites of South America (Brazil) as well as the Paleozoic ones (Argentina), to say nothing of the Mesozoic and Tertiary varieties superimposed along the faults of which mention was made before.

The structural zones of various time are distinguished in terms of metallogenic properties; the Archean and Lower Proterozoic greenstone belts are rich in gold, copper, lead, and zinc, while in the field of granitization they are rich in rare metals; the Mid-Proterozoic, or the Baikal varieties, can be correlated with the deposits of copper, lead, zinc, and cobalt; the Caledonian ones are represented by copper and polymetallic deposits (Central Kazakhstan, Northern Kirghizia). The Hercynian zones, which in some regions represent the completion of the Caledonian ones, are found to be more varied. Here together with copper, zinc, and lead there appear tin, tungsten, molybdenum, and other rare metals, connected with the acid granites that had found

a comprehensive expression in this stage of development. In the final period these zones were characterized by the formation of the deposits of antimony and mercury, that were situated at a remote distance from the sources of ore-bearing solutions.

The Mesozoic metallogenic zones that are extended in the framing of the Pacific Ocean and go far into the centre of the continents along the faults, are characterized by diverse mineralization, which in the main inherits the geochemical nature of more ancient masses of land.

Ore provinces of the sialic type with granites and tin, tungsten, molybdenum and gold deposits accompanying them, are found to be preponderant among the Mesozoic structures in the east of Asia.

The tertiary mobile belts with young and contemporary volcanic zones stretch along the periphery of the Pacific basin and in the island arcs. What is typical of them is the deposits of copper, zinc, and lead connected with the basic and median volcanic rocks, while the deposits of sulphur, antimony. and mercury are associated with the latest of them including those the formation of which we can witness.

In due time, until the Late Paleozoic period, the role of abyssal processes in the formation of ore is decreased, and the ore-bearing folded belts themselves become narrower. Beginning with the Mesozoic and Terti-

ary periods, however, round the Pacific Ocean there were evident traces of a quite different trend, which founds its expression in the expansion of the scope of impact on tectonic processes and ore formation during the activization of active structures.

Presumably the factor that conditioned this kind of resuscitation of tectonic and metallogenic activity was the formation of deep faults, which, in the eastern regions of Asia, were connected with the expansion of the earth's crust and the development of zones that were permeable for the new portions of deep-seated melts and ore-bearing solutions. It is worth mentioning that these activization processes are spread into the interior of the continents along the innovated more ancient faults, which is exactly what results in the frequent recurrence of the inherited mineralization as is the case with the gold-bearing properties of the Amur river region, and the same of tin and tungsten near the Transbaikal, etc.

The young super-deep faults have been established along the marginal part of the Pacific Ocean. Some of them are correlated with the cropping out of rocks with chromitic mineralization and the basic ones with copper. The time of the formation of some cuprous deposits (the Solomon Islands in the region of New Guinea) goes back to only three-four million years. But the formation of ore manifestations of gold

can be witnessed in some places even now. In the calderas (depressions) of present-day volcanos (Uzon) ores of antimony and arsenic are formed from the turbulent springs on the lacustrine floor.

Over the past few years no minor significance has been attributed to the question pertaining to the impact of the deep-seated structure upon metallogeny, which makes it possible to conduct the investigation in the course of the development of regional geophysical explorations carried out on a large scale. A preliminary analysis of these data reveals a block heterogeneity of the crust and the mantle, which determines the geochemical and metallogenic peculiarities of the ore regions.

The very same research helps to establish the depth into which the magma and the mineralizing faults have penetrated, to try to determine the depth pertinent to the deposition of the source of ore-bearing solutions, as well as to find the slackened tectonic zones of enhanced jointing—the channels along which the magma rises and where the circulation of solutions takes place, and in the intersection of which the ore regions are most often situated.

The metallogenic data furnish an additional material for the reconstruction of the history of our planet, the time during which its most important regions and zones were formed, and help us to determine the

faults, the features of which are blurred and do not lend themselves to be readily discovered in the course of an ordinary geological and tectonic mapping. It is they in particular, that also introduce amendments into the fundamentals of the theory of plate tectonics, refuting a considerable displacement of the parts of the outer shell of our planet, or, at any rate, in those places where its continents are situated.

Metallogeny performs an extremely important function in establishing the metalliferous of the territories that have not been adequately explored and in providing the necessary cues for the elaborate quests and exploration of the deposits.

Chapter 21
In Quest of Ores

There is no stint of mineral resources in the Soviet Union. In the age of technical progress, however, the demands in metals, coal, and oil are ever on the increase. That is why it is so important to unintermittently go on with the prospecting of mineral products.

Nowadays the discovery of new deposits presents more and more difficulties: the ores that outcrop onto the surface have mostly been already found, though the inadequately explored taiga regions, where there is some probability to find ores on the surface, do exist.

Prospecting is an arduous scientific task. The one engaged in this kind of work should possess no little knowledge in geology and the experience of practical activity. A large number of new methods are at present used when quests are conducted. They include the geochemical, geophysical and even space methods. But the old ones have not gone into abeyance either. The geologist must certainly know beforehand where to primarily look for ores.

But in addition to competence the quests first and foremost call for quite a bit of peripatetic activity. Facetiously, geologists are compared to wolves which to support themselves must constantly be on the move. To a great extent the success of any prospecting work depends on the assiduity and perseverance of the geologist. What one has to do is to examine all the accessible outcrops on the surface. The investigations around the area under analysis have a very prosaic appellation of an itinerary traversal. And, indeed, some gruelling work is called for to traverse the hills, make one's way across the dense brushwood, and not to find it too much trouble to examine the pieces of rocks (gravel) underside of a fallen tree.

This, however, is only the beginning. In its wake there comes the washing in the trough of the friable deposits from the val-

leys. What remains after the washing of light particles is the heavy concentrate with ore minerals in it. The heavy concentrate is then dried and very neatly put into small paper bags. Later it is closely studied by the mineralogists.

According to their data maps of heavy concentrates are compiled with the symbols showing the content of various minerals, after which it would be easier to conduct the quests, by focusing the attention on the most advantageous parts of the territory without any loss of time. The elaborate quests are conducted by systematically employing the tests of loose detrital deposits and bed rocks with the subsequent spectral analysis of these specimens. The tests of bedrocks as well as loose deposits are then subjected to spectral analysis.

According to the conten of a certain element in the rocks we can determine the probable distance of the test to the basic ore body: the closer it is to the ore body, the higher the content of ore elements in the enclosing rocks will be. Such a mobile component as mercury is situated at the farthest distance from the vein. This is the first feature signifying the presence of an ore body. In the propinquity of the ore itself we can find silver, lead, zinc, copper, and, lastly, tin.

The results of spectral and silicate analyses are plotted on the maps, while the map,

as we know, is already something upon which the exploration work can most readily be based.

Today the geologist is provided with diverse geophysical methods. For instance the magnetometric research can help one to show the presence of ores. It is common knowledge that the Kursk magnetic anomaly was discovered by the deviation of the compass needle, and then as a result of magnetometric operations. But magnetometry also helps to explore the sulphide ores, and primarily, those containing pyrrhotite (FeS)—the mineral with markedly expressed magnetic properties (hence, its name—magnetic pyrite). The ores are found when we study the electric conductivity of lead masses, while seismic research can serve to establish the fissures, within which ores can be discovered.

Thus, the geological map becomes supplied with new information. By analyzing all these features and comparing them with geological structure, the geologist decides where in the first place it is necessary to dig trenches so as to uncover the ore bodies from under the detrital deposits. With such powerful aids as geochemical analysis and geophysical instruments, the geologist is confident enough not to conduct the quests blind.

Let us imagine that the geologist is looking for tin, but on his map other metals

are also indicated by means of lines of different colour. In addition to the red lines, showing the tin, we see the blue ones for lead and the green lines marking copper. These metals are the associates of tin and also helpful in our prospectings of ores. Sometimes the coloured lines coincide with exactly the same parts of the map, while in other cases they do not. Where then should we dig the ditches first?

Certainly in those places where there are greater quantities of tin! This is absolutely so, though we cannot be absolutely sure that what we have before us is the best veins. Let us also focus our attention on the oreoles of lead, and particularly where tin manifests itself at least a little. There is much greater probability that it is precisely in these ore bodies that the most promising veins are embedded. Here, presumably, the uppermost parts of ore veins that are rich in lead are only somewhat exposed on the surface, and, consequently, one may as well suppose that the vein goes deep down and the emergence of ever-increasing amounts of tin may be expected too.

In assessing how promising the deep horizons of veins can be, the geologists are guided by their knowledge of the zonality of mineralization—the regular alternation of some of the metals by others.

Now, the correct and opportune evaluation of the 'depths' is highly important for

the solution of the question whether expensive mining operations should be conducted here or not.

The study of the depth and zonality of mineralization is exactly what the team of the Far East Geological Institute has been carrying out for some time. We investigate the specimens of ores and rocks in mine workings. It occurs that the depth influences not only the composition of the principal ore elements, but also the content of the so-called admixture-elements. The number of these admixtures can be infinitesimal (even ten-thousandths of one per cent), but they serve as the most significant indicators of the depths pertinent to the formation of ores.

For instance, the lead lustre from the upper horizons encloses more silver, while that from the lower ones includes a greater amount of bismuth. Thus, the analyses of the lead lustre help to estimate how deep the ore vein has been exposed and whether its continuation into deeper regions could be expected. The content of admixtures in tin stone (cassiterite) undergoes changes too. In the upper horizons this mineral contains a greater amount of scandium. With the increase of depth we can find more indium and tungsten, while in some of the deposits, depths function as a prerequisite for the emergence of tantalum. This 'company' of admixture-elements is characteristic of the tin stone, which is formed at high

temperatures, and which is found in the deep horizons.

This kind of research calls for quite a bit of work. The sampling in dark and damp workings is followed by their description, study and the selection of the so-called monomineral fraction (pure mineral) under the binoculars or the microscope. The selected material is then subjected to spectral, chemical and other kind of analyses. Many thousands of samples in the tin deposits of Komsomolsk ore region have been studied by us in this manner. Our efforts had proved to be not in vain. We were fortunate in that we managed to successfully employ new data for the recounting of the reserves which proved to be more considerable than what we had previously expected. We proved that it was necessary to take into consideration the value of not only the main element—tin, but also its associates. Hence, a large number of supplementary conclusions can be derived from the statement, viz. that the contours of ore bodies have changed, that it is necessary to change the processing technology and create new plans for the enrichment and an overall extraction of all valuable components.

We have one more method at our disposal with the help of which we can determine the depth of the formation of ore bodies and evaluate how promising their descent into still greater horizons can be. This is

the so-called method of thermobarometry, i.e. the investigation of the gaseous-liquid bubbles in minerals, or the remains of the 'preserved' mineral-forming solutions. This is an exceptionally subtle method requiring no little effort, a great deal of elaborateness and perseverance.

The fact is that our minerals—the ore ones (cassiterite, tungsten, and sphalerite) are the non-metalliferous varieties (quartz and calcite), while being formed from aqueous solutions, had 'buried' in their crystals the remains of these solutions, and it is precisely they that provide us with the main information about the conditions pertinent to the formation of ores. The scientific research in this field is being carried out by Anatoli Kokorin and his wife Dina. Here the number of definitions finds its expression in many figures, as is required by any statistical analysis.

Under the microscope our colleagues are examining small gaseous-liquid bubbles in the polished transparent thin plates of quartz crystals. The number of such bubbles within the crystals is very great indeed, and they are of quite different nature. What presents the main interest is the so-called primary inclusions, the buried drops of the ore solution. Under usual indoor temperature these drops contain gas bubbles of various size, and sometimes one, two or sever-

al hard minerals as well. They are the so-called captive-minerals.

What is most often found is halite (common salt) in the form of transparent little cubes, sometimes sylvite (potassium chloride), calcite and other transparent minerals. They show that the solutions were rich in chlorous compounds of alkali and calcium carbonate. It is even possible to estimate the content of these soluble salts.

Gradually and with no little patience the researchers select the samples of minerals from different horizons of the deposits and establish how the temperature changed as the ore-bearing solutions were making their way towards the surface. If within the ore bodies they find low-temperature minerals, they become imbued with hope: this means that with the increase of depth minerals of higher temperature will emerge, and, thus, the ore body can be traced to a great distance, into the bounds of the Earth. If, however, the definition of quartz which was discovered at the outcrops of veins, reveals a high temperature of its formation, or, what is more important, a high degree of saturation of the solutions with various salts, it means that the part of the territory in question is lacking in any good prospects as far as depth is concerned and what we have here is only the exposure of the 'roots' of some vein. These data together with the chemical and mineralogical

information, in conjunction with the research into the forms of crystals, which are also liable to undergo vertical changes in the vein, are used in assessing the continuation of the ore bodies in terms of depth, which is of no minor importance for purely practical purposes.

But, unfortunately, all this is not always as easy as it may seem. In some of the deposits the solutions have been rising from the depths not infrequently. This is exactly what we found to be the case in the Kavalerovsky district in Primorye, where it occurred that the tin mineralization had been developing for at least 20 million years.

And thus we have been confronted with a new task which consists in the interpretation of the history of these various and multi-stage ores of different age. Each of the stages of this highly complex ore formation had its own characteristic features and particular regularities in the distribution of metals.

Long time ago the students of the mining and metallurgical faculties of the Leningrad Mining Institute scorned the geologists. In their opinion all one had to do to become a geologist was to get hold of a stick and whistle the dog. It was certainly a joke. Now you are becoming more convinced that geology is a difficult branch of science. The geologist is at one and the same time a researcher, a scientist, an engineer (the manage-

ment of mining operations), an economist (estimates, accounts, projects), and a psychologist (the work involves many people as members of teams and expeditions). The profession of a geologist is complicated and fascinating, and what is most important about it is that every nation does require it. The geologists make way for the miners and for the construction of mines and concentrating mills.

Chapter 22
At the Metallogenic Map of the Pacific Belt

What I have before me at the moment is the metallogenic map of the Pacific ore belt. We have been compiling it for as long as nearly twenty years. During the first years of this period my constant assistant was a young woman, a cartographer, who most assiduously plotted all the deposits on the map, and used different colours for rocks of diverse age and composition. She did her work with a creative zeal and was always ready to support her own opinion which at times seemed to be quite original. In many questions she was more at home than those who had degrees in geological sciences.

The work on the map continued with my assistants. Quite a few problems cropped up with the map. How to correlate different projections and work out a single scale for all the variants? This work was tackled by

one more of my assistants, a draughtswoman.

And now the map is completed and published. It looks splendid. The coloured ring of the ore-bearing zones surrounding the Pacific Ocean is most vividly presented. As in absolutely all geological maps colours are used to show the age of rocks: the Triassic period is violet, the Jurassic is blue, and the Cretaceous age is given in green. Scarlet spots contrastively distinguish the massifs of granites. They are the ones that immediately strike the eye. The coloured circles, squares, rectangles, and rhombs indicate the deposits: the blue ones show lead and zinc. The red figures stand for tin, those of the brown colour designate tungsten: copper, gold, and mercury are given in green, yellow and crimson respectively. Their number is very large with 1500 deposits plotted on the map.

The deposits are arranged in the form of narrow bands called metallogenic zones, parallel to the coast of the Pacific Ocean. There are 218 zones of this kind on our map. Each of them has its own profile and is distinguished by its typical set of rocks. Some of the groups of deposits form chains that look like beads threaded on a line drawn in red pencil. These are the ore-conducting and ore-controlling deep faults, or fissures in the earth's crust, along which magma and ore-bearing solutions had been delivered.

Most of the ore-bearing deposits in the Pacific ore belt are young and belong to the Late Mesozoic or Tertiary periods. But in the outer framing there are belts that are ancient Paleozoic ones, and even the Pre-Cambrian deposits.

Looking at the map, it is possible to imagine various parts of the Earth's history in terms of time.

Now, this is where we have the Aldan shield—the crystalline ancient nucleus of the Siberian platform. Its eastern part is continuous with the Sea of Okhotsk and is separated from it only by a belt of Jurassic and Mezosoic volcanites. On the Aldan shield we have the exposure of ancient Archean rocks. Their formation goes back to the early stage in the development of the Earth.

The most ancient rocks of the Aldan shield are known to be rich in ores: this includes ferruginous quartzites, magnetite skarns, micas, and apatite ores.

It would be quite desirable to actually form a clear-cut idea of what the Earth of that period was. And even what it was like in a still earlier stage, when this region was characterized by the outflows of basalts. Even now these domes can be seen in the general structural pattern of the ancient massif. They can be discerned in the aero- and space-photographs by the rounded concentric contours that reflect the deep structures.

The blocks of the ancient rocks are also found in the mountain-folded frame of the Aldan shield—in the Stan and Dzhugdzhur ridges. These ridges pass along the most important faults that emerged during the fracturing of Pangae, when the Siberian and Chinese platforms were separated. There appeared a mobile zone, in which frequent subsidences took place. They were the ones that were at times replaced by folding, the elevation of mountain structures, their washout, and the sinking of upland territories.

This is where we have the famous Mongol-Okhotsk folding belt, called so by Academician E. Fersman. We can see a large number of red spots on the map. They are the massifs of granites belonging to different age-groups, e.g. the Pre-Cambrian, Paleozoic and Mesozoic periods. They are connected with diverse and non-coetaneous mineralization. What has received a particularly great development here is the mineralization of the Late-Mesozoic period.

The deposits within this belt are situated in the parallel zones. In the southern part of the belt we see the blue zone. It is the polymetallic belt of the Transbaikal. Every single dot on it carries a great deal of information. I visited the old mines in the period of their reconstruction after a break covering some fifty years. With unabated interest I examined the mine workings

where at one time in the history of Russia the Decembrists were sentenced to hard labour, and where Prince Volkonsky's wife kissed her husband's fetters on seeing him in durance vile. At present, after thirty years of exploitation, these historical workings have already been destroyed, but then they had remained in their original state. The lead and zinc deposits of mass ores were markedly distinguishable against the background of light limestones.

Almost all the lead and zinc deposits of the Transbaikal are found among the limestones. The same kind of correlation can be discovered in a large number of other lead and zinc regions of the world.

Tin is shown to the north of the red striated area. The red lines alternate with the brown ones, or those that indicate tungsten. These two metals—tin and tungsten—constantly go together, just as lead and zinc. But the enclosing rocks for tin and tungsten ore bodies are already quite different. They are not limestones, but sandstones, schists and aleurolites. Not infrequently we can find in this zone massifs of granites, around which or in the granites themselves deposits of tin and tungsten are situated.

Places that I still remember are connected with this tin and tungsten zone. Those were the thirties of the present century, the time when the recovery of tin and tungsten in the Transbaikal was only at the outset.

Today quite a few deposits have already been developed and the settlements of miners have become uninhabited.

Farther to the North we have the yellow and violet striation showing the gold and molybdenum zones. They pass along the faults far to the east across the Primorye and right up to the coastline of the Sea of Okhotsk. The deposits are of different age, but the most important of them belong to the Late Mesozoic period, with those of the Tertiary age in the east.

Along the eastern margin of the Asian continent and the shore of the Sea of Japan we have the Sikhote-Alin folded Mesozoic belt. It is characterized by exactly the same regularities as the Mongol-Okhotsk belt; among the sandstones and schists the tin zone is located, while the lead and zinc zone is located amidst the limestones. Each metal has its own 'favourite rock', within which it is most often concentrated. This may probably be explained by the fact that metals have been adopted from sedimentary rocks.

One of the peculiarities of Sikhote-Alin is the volcanic belt on the border between the land and the sea. Just try to imagine this kind of situation which hardly seems to be credible: for millions of years thousands of volcanoes have been ejecting huge clouds of incandescent ashes. The wind carries it over great distances, though most of the

ash falls right here, filling and smoothing the depressions of the relief. From the funnels of other volcanoes the lavas flow out in fiery streams and get mixed with the ashes that are still falling or that have already reached the ground. These streams are once again superimposed by the ash cover, and this is how thick masses of volcanic rocks have been formed (some of them measuring hundreds and even thousands of metres).

The vent funnels served as channels along which in the later period hot ore-bearing solutions with tin, tungsten, lead, and other metals were rising from the depths. In the fissures the solutions were depositing their precious load, and that is how the ore veins originated.

The author has traversed many hundreds of kilometres through the wanton subtropical taiga in the coastal region, making her way across the impenetrable brushwood and the splicing of lianas, and the dots plotted on the map of Primorye are by no means an abstract notion for her, but always an active memory about the characteristics of each of those places, and the people who discovered and explored the local deposits.

Reminiscences also draw me to the regions of North Korea, the country of high mountains, full-flowing rivers and rich ores. The small Korean peninsula is for-

tunate in that nature has given it an ample supply of such valuable metals as iron, copper, lead, zinc, and tungsten.

The South of China is also a rich underground storehouse of our planet. Here we can find enormous concentrations of tin and tungsten, lead and zinc, antimony and mercury. This region of the Pacific ore belt is rich in all the metals we know of.

The author happened to find herself in the famous ore-bearing district of Gedzyu—the 'metropolis' of tin. From the high upland we came down into the stifling valley of the Red River, where the thick crowns of tropical trees shield the light of the Sun and do not admit even the slightest whiff of air. Later the author saw the Red River at a closer range from the shore of Vietnam, where she examined the old workings at the deposits of tin and tungsten.

Her peripatetic nature also took her to the far-off regions of Australia, where the author made herself acquainted with the deposits of lead and zinc, tin and tungsten. This is the continuation of the Pacific belt, though the age of the deposits here is more ancient (Paleozoic and Precambrian).

But on the other side of the Pacific Ocean we have the preponderance of the young deposits belonging to the Cretaceous and Tertiary periods. One of the characteristic features of the North-American branch is that it is rich in copper, gold, silver, lead, zinc,

and molybdenum; tin being typical of the South American region.

The author was fortunate to have accomplished two geological excursions: across The Rocky Mountains and the Cordileras of Canada as well as along the Mexican upland. It goes without saying that no brief itineraries can suffice in order that we could get some idea about the metallogeny of this very rich branch of the Pacific belt. And yet personal impressions help to better understand the material, which one receives when analyzing the maps and reading the scientific literature on the subject.

It occurred that there was very much in common between the deposits in Mexico and Primorye with which I am so well acquainted. When we entered the ore manager's office at the lead and zinc mine in Santa Eulalia, what we saw on the walls included plans and profiles of the ore bodies, while on the table there were large pieces of ores. Like silky stars the crystals of dark-green radiate hedenbergite are shining and against its background the anthracite-black zinc blende (sphalerite) and grey silvery lead lustre reflecting the sunrays on the fragmental planes of cubic crystals are conspicuously distinguished. If for only a fraction of a second we disregard the foreign speech, we can very well imagine that we are back home in the same kind of office in Primorye. The ores are very much alike,

and the same could be said of the diagrams illustrating the morphology of ore bodies. Paying special attention to the relationship between the ore veins and the veins of igneous rocks, and their connection with granitic massifs and covers of young Tertiary lavas, I cannot but point out that there is much in common between them and the ore-bearing regions in the USSR.

In the American branch of the belt (just as in the Asian one) most of the lead and zinc deposits are situated in the limestones, particularly in Mexico, while the tin deposits are found in the sandstones and schists of Bolivia, the gold and copper deposits can be discovered in the lengthy faults, which seem to extend over thousands and more kilometres (for instance, in Chile). It should also be mentioned that vent funnels are found to be correlated with the largest concentrations of copper with molybdenum and gold.

However, in spite of similarity, there exist substantial differences between the branches, that determine the asymmetry of the belt. A peculiar characteristic feature of the American branch of the Pacific belt finds its expression in the long and narrow granitic massifs, which correspond to deep faults.

The Asian branch of the Pacific belt is more complicated in form and structure. It is only on the Asian side that we can see

garlands of island arcs, which are traced from Kamchatka across the Kuril Islands, Japan, Taiwan and the Philippines to the Islands of Indonesia. On the American side these island arcs in the Pacific basin cannot be found at all. They are seen only to the east of Central America within the confines of the Caribbean Sea. Isn't it possible that this kind of asymmetry is the result of some planetary factors, such as the rotation of the Earth, which could greatly influence the separation and detachedness of the blocks of continents in the course of its rotation?

The Asian branch is much wider in its continental part: its ramifications ('bays') penetrate deep into the continent along the transversal ancient folded zones. On the same plane with these zones there appeared faults, in the proximity of which we find the propagation of young 'crustal' granites, accompanied by tin and tungsten mineralization.

The metallogenic research in the Pacific ore belt sets before itself the aim of not only achieving a comprehensive planetary analysis, but also an elaborate investigation of individual ore provinces so as to establish the regularities pertinent to the distribution of metals within them.

All these questions are being solved by large bodies of geologists, in addition to which a substantial aid in determining the

regularities of the location of the deposits and the correlation of metals with particular types of sedimentary and magmatic rocks is nowadays rendered by a subtle geochemical scientific research. This kind of work is carried out in the Far East Geological Institute, the main task of which consists in the study of those regularities which are associated with the distribution of the deposits of the Pacific ore belt, as well as the characteristic features of the development of the zone of the transition from the continent to the Pacific Ocean.

Chapter 23
Mineral Resources of the Seas and the Underwater Storerooms of Mineral Raw Materials

Until now we have mainly been concerned with the mineral resources of land. The land, however, occupies only one-third of the Earth's surface. The remaining two-thirds are covered with the waters of the oceans. Do we have mineral resources there?

The answer is most emphatically in the affirmative! First and foremost the principal sources of mineral products are the ocean waters themselves. They contain practically all the elements of Mendeleev's periodic table. Sea water already deals its numerous components. By means of evapo-

ration we receive salt, while on an industrial scale there takes place a recovery of iodine and partly bromine (which is derived mainly from the algae). In the enclosed and semi-enclosed basins in the bays we have the plantation and recovery of various salts (Kara-Bogaz-Gol).

According to A. Vinogradov sea water contains dissolved salts of quite a few metals, such as lithium, sodium, potassium, magnesium, calcium, and strontium. Those of the non-metals include chlorine, bromine, iodine, fluorine, and boron. There is some reason to believe that in the course of some time more elements, including gold, will be recovered from sea water. The press has not infrequently informed us of a high content of gold (upto 6 milligrammes in a ton of water) and the incredible estimates of its general resources (almost 8 trillion tonnes) in the sea! Later it occurred that the content of gold in water was one hundred times less than what was previously mentioned. But the interest to the problem of its recovery from sea waters has not waned. For this purpose various means are being suggested. One of them is the use of plants and animals absorbing gold from sea water.

We have been carrying out the research into the content of gold in diverse algae and animals together with the group headed by Galina N. Saenko, Cand. Chem. Sciences,

of the Institute of Chemistry of the Far East Scientific Centre. As a result of our joint efforts we have been able to discover certain types of algae and mollusks containing increased quantities of gold and other metals.

What then are the factors conditioning the enrichment of sea and ocean waters with salts? The main suppliers of salts are the products of underwater and terrestrial volcanism, as well as the products of destruction and decomposition of rocks on land that are delivered into the seas by streams. The disintegration of rocks into their components also takes place on the ocean floors under the impact of volcanic gases and solutions, as well as the mineralized sea water itself. This is how basalts are decomposed. What is subtracted from them by leaching includes iron, manganese, nickel, cobalt and other metals. Presumably, these processes lead to the formation of oceanic ferromanganesial concretions!

This may also have been the means of formation of the recently discovered iron-like masses of sulphides of zinc, lead and other metals on the floor of the eastern part of the Pacific Ocean and the Red Sea. These masses cannot yet be called ores, though they are undoubtedly the future ores, which helps us to understand the processes of the concentration of ores of sedimentary origin in the remote geological past.

What is of no minor practical significance is the mechanical concentrations of heavy minerals on the shelf—in the littoral shallow-water part of the sea. Sea waves do an enormous amount of work connected with the sorting of the material that is delivered from land. Heavy minerals are deposited near the shore or on the beaches. Their accumulations are highly significant: the main part of the world output of titanium, rare-earth and some rare elements takes place at the expense of the development of sands at the shelves and beaches, particularly near the continents of the Southern Hemisphere, where the weathering out of the rocks of land is also more intense, in addition to which the bedrocks of the continents themselves, which are represented by the ancient metamorphic masses, are enriched with valuable admixtures. They are the largest placers of Eastern Australia, Sri Lanka, India and Brazil.

From the floor of the seas we also extract tin and gold, mainly from the placers that were at one time formed on land and then submerged under the sea level. The recovery of tin stone (cassiterite) is conducted near Asia Minor, Thailand and the islands of Indonesia, sometimes at a considerable distance away from the shores, which can be as great as about 30 kilometres.

The author's pet daydream to visit Asia Minor—the land of tin—has not yet been

realized. In fact, she did visit Thailand; on her flight there she saw the Malacca peninsula with neatly arranged dumps, the traces of dredges, that looked like sand cakes made by the children playing on the beach. She also saw the emerald lakes within the frame of brightly-red clays in place of old quarries with the glowing green tropical forests in the background. On her flight from Singapore to Australia she saw bright-green islets of Indonesia with steep hilly precipices and the shelf shallow waters surrounding them, through the shoal it could be seen the dark threads of submerged river valleys. In the sea below dredges were doing their work too.

After that a group of scientists began studying the fossils on the shelf of the seas in the Far East. The Sakhalin geophysicists were very kind to let them have the boat *Geofizik* which could meet all our requirements perfectly well. It has enough space for our equipment, the dredger that was supposed to operate on the bottom and the then first in the Far East 'Sparker'—an instrument for the investigation of the sediments by means of reflecting the sound waves.

In order that you could have an idea of what exactly the marine geologists are concerned with, I should like to say something about our itineraries. We did the work in separate groups. In the boat we tested the samples of the ground, took radiometric

and magnetometric measurements and did the uninterrupted seismic profiling. The other group in their small motor-boat, and sometimes aboard two boats of this kind, studied the shores.

What we still particularly remember comprises our routes along the islands of the Minor Kuril arc. In the motor-boat the motorist, the 'captain', the biochemist, and the author conducted the tests of the rocks of exposed sediments found on the beach. There were quite a few happenings, even the unfortunate ones, in the course of our work. For instance, during the longest transition from the island of Tanfiliev to Shikotan our motor failed to function normally. For more than an hour the boat drifted at the mercy of the waves and the wind only to find ourselves shrouded by an inspissated fog. By the time the boat was floating, we lost the way altogether, and when the engine started to work again, nobody had an idea where to go at all.

I tried to prevail upon Radii to go north, lest we should find ourselves in mid-ocean. Who would have been able to save us there?! We argued for some time and finally decided on what I had suggested. We continued to sail with the long-awaited island of Yuri still not in sight. Fog was everywhere. Was it possible that we were heading straight for the ocean? On either side of the boat two very pleasant dolphins were accom-

panying us as though they were the escort of honour.

Suddenly at a distance of 20 metres ahead of us we managed to discern the precipitous hills covered with a thick blanket of fog. Thank God, we did not run into them. As we discovered later it was an island indeed, though not the one we expected to land on. It was the Zelyoni (Green) Island! No other word but 'luck' springs to my lips when I think of how fortunate we were to get into a little patch of an island in the comprehensive ocean.

On another occasion we lost our way in the fog and could not get in touch with our station vessel, which failed to respond to our radio signals. The dark summer night had already covered the Earth and we continued to sit on the shore, making campfires and feeling not cheerful at all. Then, we went up to a high terrace and received the signals coming from the *Geofizik*. It was only at two o'clock in the morning that our colleagues, anxious for our fate, had met us at long last.

It was exactly the same on the morrow. We again went out in our motorboat to enter the fascinatingly beautiful bays, help Nina to gather algae, and take samples of hilly rocks and sand tests.

How superbly divine the underwater kingdom is! Like locks of hair the wave stirs the long emerald-green and crimson

algae, with shoals of fish moving hastily in-between them. The sandy floor serves as the bed for the round black sea urchings bustling with their long acicular spines. The orange and lilac starfish spread their rays burning like fire. Sometimes, however, we managed to find corallites on the bottom. The aqualungs were aboard the vessel for deeper submersions, and what we could avail ourselves of were only the masks.

On that day we could not get in touch with the vessel for a long time either, though now our orientation was faultless. We were going round the big island of Shikotan and it was next to impossible to lose our way. The fog was becoming thicker. The sky was clouded, and at last we heard the instruction. We continued to move and meanwhile expressed our disagreement with the captain, whose instructions, we thought, would make us collide with the rocks.

What the radio was saying was 'Follow the light of the ship!' What could it have possibly meant? The fog was most gloomily caliginous. And yet there did glimmer a light. We rushed towards it! As we were approaching it, it continued to draw us to itself ever closer. But there was no ship in sight. We were moving straight in the direction of that light. And all of a sudden there appeared through the fog a scattered glow of golden oreole which was getting more and more blurred. The ship was right before us!

And as for the little bright dot that was drawing us closer to itself, it turned out to be a lonely star shining through the dense clouds. We could do nothing else but thank our lodestar for bringing us safe and sound and aboard the ship we had been heading for!

How comforting the ship seemed to be after our peregrinations in that fragile boat of ours! And as for the supper, it simply melted in our mouths!

When the next day came we were back at work again, finding ourselves in the unbelievably beautiful bays of the eastern coast of Shikotan, while in the deep fiords we were met by the frightened birds that covered the hills and stores in large quantities of their settlements. The black cormorants were keeping guard with their widespread wings producing in each case the impression of a cross. It also took quite a bit of time for the silly little things to run about the water surface, flapping their wings in their attempt to fly high into the air.

We were supposed to meet the ship in the bay of Minor Kuril Islands, but it occurred that it was much more difficult to achieve this in a 'civilized' bay rather than in the wild ocean. A mass of saury-fishing boats with wing-like plates carrying lights practically blinded us quite unexpectedly. Where was it then possible for us to find our *Geofizik* among all that conglomeration of ships? Another unfortunate occurrence had await-

ed us: the rope with which we dragged a long mast-like bamboo of about twenty centimetres in diameter got stuck in the propeller. Where was it from: the South of China? The Philippines? ...

It was dear to us as a memory of our exotic voyage, though we owed our halt entirely to it. We stood still with the huge mass of a ship coming straight upon us. A student of our group lost no time. He hold of a portable lamp and started waving it over his head. The signal did not remain unheeded. The saury-fishing ship did not crush us.

This was how we roamed along the shelf of the Sea of Okhotsk. There were quite a few interesting things connected with it. It was established, for instance, that near the place where the hot stream flowing from the slope of a volcano entered the sea, in the sediments of the shelf and particularly in the algae, the content of ore elements was much greater than within the other parts of the territory. This can actually serve as evidence of the rotation of matter: volcano—its hydrothermal activity—the organisms on the sea floor—sediments. All this seems to function as a kind of stock for the geological and metallogenic processes of the future.

After that the expedition continued its route without me. They passed along the whole perimeter of the Sea of Okhotsk. The

young people dived and examined the continuation of ore veins under the water. The hilly exits were covered with a thin delicate film—the verdure of algae, which did not prevent us, however, from finding the ores under the water surface. On one of the islands of Minor Kuril Ridge they suddenly came across lumps of granite: prior to that period granites were not known to exist on the island. It was considered that the island arc in this part of the country 'developed' mainly upon the basalt foundation deprived of the granitic layer.

They stayed for some time near the Shantar islands, where features of the remote dislocations of enormously large lumps of granite melted into ice were discovered. It was very difficult to work within the zone of the Shantar islands: in the permafrost the ground froze into a monolith, and they were obliged to test the sand by actually cutting their samples as though from a mass of concrete.

On a number of occasions I went to the other parts of the littoral zone too, and everywhere found it very interesting to observe the processes taking place on the coast. It is precisely in the narrow edging of the shelf that the life finds its most coherent manifestation in spite of the intense surfs and storms. And yet these waves have some gifts in store for us. Here in the sand on the beach we can see lilac and rose-coloured 'crystal fragments accumulated on the crys-

tal's upward face' of garnets, and black magnetite grains in the other places. The storms wash and dislocate these hard sands. It becomes clear now why the development of sands is conducted rather frequently: at the place of extracted heavy sands the waves deposit the new ones. All this is an infinite 'factory' of the concentration of heavy metals on the shelf.

The accumulation of metals in the algae and the tissues of mollusks leads to the enrichment of benthonic sediments with them. Then getting into the scope of the activity of magmatic rocks or hot solutions, these metals dispersed in the sediments can migrate and in certain conditions give rise to ore deposits. Such is the geochemical circulation of matter: volcanic solutions—sea organisms—benthonic sediments—ore veins. The washout of veins and the removal of destroyed material into the sea upon the shelf take the elements back into the sea water. The significance of these cycles was brought out by V. Vernadsky.

According to A. Vinogradov, the living organisms contain on the average 70 per cent of oxygen, 18 per cent of carbon, and 8 per cent of hydrogen. The content of the other elements is in the main close to those contained in the earth's crust. However, some of them are concentrated in the living organisms. They include phosphorus, which the organisms contain 10 times more than

what we can find in the earth's crust, three times more iodine, and 100 times more radium.

Organisms selectively accumulate particular elements, for instance, the mollusks concentrate strontium in their shells. The layer of these shells may well be regarded as a prerequisite for the formation of sedimentary deposits of calcium carbonate and sulphate of strontium. The concentration of phosphorus by the mollusks becomes responsible for the formation of sedimentary phosphorites. Some of the plants and animals adopt gold. Its content in them is 100 times greater than in sea water. There are mollusks in the shells of which a substantial role is attributed to zinc carbonate. Isn't it what conditions the origin of bedded deposits of zinc sulphide ores?

What is most valuable among the sediments is the ferro-nikel concretions, which abundantly cover the ocean floor in some of the regions. Their recovery is something that belongs to the nearest future.

Moreover, the shelf serves as an important source of oil, the placers of heavy valuable minerals: diamonds, gold, and tin stone.

Chapter 24
Save Our Earth!

Ever since the advent of Man, the Earth has been his mother and wet-nurse.

Within the millions, thousands, hundreds and even tens of recent years people had been in a state of relative equilibrium with the environment. Nowadays this balance is catastrophically being disrupted. The progress of the industrial activity of man that the present generation can witness for itself is fantastically on the increase. I still remember the transition from the kerosine lamp to electricity, from the first radio sets to television, from the dreams of science-fiction writers about interplanetary flights to their actual accomplishment, from the use of cannon balls in World War I to the destructive atomic weapons at the end of World War II.

But how can we possibly compare all the wars of the past with what might turn out to be the war in the future? Those who are insouciantly preparing this kind of war threaten to destroy not only the whole mankind, but also its culture, and all that has life in general. But is it for this purpose that life, which has been developing on our planet for billions of years, would be destroyed at the will of asinine fanatics? And yet this jeopardy is becoming ever more tangible. It was apparent in 1944 to V. Vernadsky, who even suggested the means of its suppression.

'At present we are experiencing a new geological evolutional change of the biosphere. We are on the threshold of noosphere. We

are entering into what may be regarded as a new spontaneous geological process, into the menacing time and the epoch of a destructive world war.

But what is important to us is the fact that the ideals of our democracy go in hand with the spontaneous geological process, the laws of nature and are congruous with the noosphere.

Hence, it is possible to feel confident about our future. It is in our own hands, and we shall not let it be 'jeopardized.'

As is indeed the case, all people of good will, irrespective of their social position, stratum, nationality and political convictions are amalgamated in their struggle against the threat of war. And we do believe that reason will eventually take the upper hand!

But even the peaceful activity of man has its deteriorating effect upon nature, however less catastrophic than war, it may seem.

At the time of the current technical progress the activity of man results in its transformation of the Earth, with the emergence of new seas, the change in the direction of river-beds, the expanse of land, recovering the space from the sea, the inevitable disruptions of landscapes, which cause an irreparable harm to the environment. For instance, forests—the principal source of life, giving oxygen—are becoming ever more rare

on the surface of the Earth, water and air are in the process of contamination.

What causes a particularly great damage is the mine workings where the blame can be set on us, the geologists, and our colleagues—the miners. In the work of the American scientist R. Smith, which has already been mentioned, it is said that one third of all the wastes of human activity which pollute our environment, is accounted for by the dumps of metallurgical production. Enormous quarries remain in place of the recovery of iron ores, phosphorus raw materials, copper, lead and zinc, to say nothing of coal. The open-cast mining of coal in the quarries, as the most progressive means of recovery, is on the increase from year to year: if in 1920 it comprised 29% in 1953 the figure was 51, while in the year 2000 it will reach nearly 60% of the overall production of coal. This seems to be quite encouraging since the exhaustive labour of the miners is going into abeyance. And yet the wounds inflicted to the Earth in the course of such mass open-cast minings are not easily healed for the most part, though there exists every opportunity to level out the huge cauldrons, and plant gardens and forest on top of them, and do everything possible to isolate the dumps with hazardous substances, as, for instance, with sulphides at the expense of whose oxidation the rivers become supplied with sulphuric acid, as well

as poisonous compounds of arsenic, lead, and mercury.

These questions are being very closely studied. In this country laws have been adopted ensuring the protection of mineral resources and the environment.

Strange as it may seem but the boundless waters of the ocean are now found to be under the threat of pollution. Frequent accidents with the oil tankers may well serve as a cogent example of it. The ever-increasing volume of oil transported by sea is not a minor threat either. Yet giant tankers, ships of up to one million tons displacement, are designed at present. According to Smith's estimate, this figure can be reduced to only 800 thousand tons. He writes that the sinking of one of such giant tanker can increase the contamination of the World Ocean by 25% in only a single case.

What is an incredible jeopardy for the ocean is the containers with radioactive wastes, which are submerged by some countries into the ocean depths with the hope that they would be preserved there. But who can guarantee that they will not be driven by the deep currents in other parts of the ocean where the leakage of deadly radioactive compounds can take place? The world community raises its voice in defence of the ocean.

The wastes of technical products, i.e. the waste gases and smokes entering the at-

mosphere and which can also change its composition, are also dangerous.

The questions that have been touched upon are only a part of one general problem pertaining to the protection of the environment. Its solution is promoted by the international conventions, conferences and symposia. The inhibitor in this struggle to protect the Earth is the Soviet Union.

I am a daughter of the Earth,
And heed its every call.
I want to grasp the sunbeams without dearth
And say, 'Let's save our planet, the one and only planet among planets' to us all.

These are the general problems for the whole Earth. We have but a single planet, it is our home, and its fate concerns all of us.

To End on a Poetic Note

To End on a Poetic Note

Along the meridian the Soviet Union covers the territory from the Black Sea in the South to the White Sea in the North. The Carpathian Mountains and the Kuril Islands enclose this vast country along the latitude. Anywhere you go, you will find thousands of geological teams with the geologists working hard in the fields. The work is fascinating though by no means easy; and it is only the one who is ardently devoted to his or her profession that can bear the many difficulties of explorations.

I find geology so absorbingly interesting that for me its romantic aspect and poetry go hand in hand with what is purely scientific, and at times I cannot refrain from rhyming my thoughts about my research and practical experience.

I have already introduced some of my verses in the opening chapters of this book. In its last pages I should also like to speak of the difficulties and pleasure of the work that the geologists are doing in different parts of my country.

Then why not have some of my verses feature as a kind of afterword.

Beyond the Polar Circle

The boundless snow-field where the North
Pole breathes,
And downhill run the deer,
Without respite, unslothfully;
Let's hope the camp is near.
Come on, let's hurry, hurry,
And in the snow-storm flurry
Our winged sledge moves on.
To warm our hands and feet,
And then have something to eat;
And after a night of rest
To go back to tundra — the merciless tundra —
for quest.
Here is the spring with the daylight not fading
Beautiful colours, enchanting, pervading.
Dim and short are the shadows
Cast by the slender and fragile plants.
In the pale crimson light of the morning
It's the birch-tree that enchants.
A very small flower right on the spot
Shines in the moss like a minutest dot.
And all the flowers yellow and blue
Will appear on the surface after the dew.
The vernal wind stirs the birch-trees in the air.
We hear the sea gulls sobbing over the mer.
And things that broke off from a greater floe
Succeed each other in their flow.
Big chunks of ice are rocking in the crevices
And we expect the caravan in our premises,
With letters, goods, and all such things
It's a real feast that this messenger brings

When evanescent autumn clothes the tundra
with the proper gown,
It is the time of its mourning, for winter
is coming down.
When howlings of the snow-storm will not yield,
And there will be no man seen in the field.

Yet rich is the fruit that our labour bore
In peopleless tundra we found the ore.

Tin and diamonds, copper and gold,
Where oil and gas will shortly be unfold.
This wild and untrodden part of the world
Has many a treasure in soil so cold.
Hard as it is to work in the tundra
All the geologists cannot but love it.

Near the Amur River Region

The gloaming near the Amur River in taiga,
With light that glimmers through the firs,
And curly moss as light as air
Is driven by the wind to form a smoky cloud
somewhere.
But in the pathless thicket far away
We see more people coming every day.
They are the builders of the railway near Baikal.
And now the trains move through the woods.
Like ships that make their way in a canal
So as to make the cities shine at night
And have the railway ramify its routes
More work geologists now have to do
With new points on the map appearing too,
And gold, and tin, and iron ores
Awaited by the mines have them in stores.

Primorye

A little to the South, right near the sea,
Where sea itself is blue and hills are green.
And plants below the surface of the water can
be seen,
And then the oaks that crown the hills
With craggy little trees
The sight of which our eye does thrill.
And now we are amidst the thickest wood,
Where every elm to sky protrudes
And like a giant stands above the clouds
With whitish trunks that cotton shrouds.
And the lianas hinder every move we try to
make
Like shackles that prevent us further step to
take.

Sharp are the contrasts of shadow and light
When plants are in wantomness of sheer delight.
The scent of the lilac is stifling indeed.
With vapours in taiga that always proceed.
It's difficult to find our way
In the subtropics close to sea, as we may say.
Yet the geologist in quest of ores
Has neither time, nor wish to pause.

Central Asia

Is there much misfortune everywhere?
Oh, no. By far not so at all.
In arid Central Asia the problems do take toll.
You would be seeking shade in vain
Among the maze of rocks,
Where every curve is burning hot
And yields protection not.
With purple rings before our eyes,
And scorching, stifling thirst.
The tired steps are heard no more
And in my ravings on the sandy floor
Exhaustion is what I feel first.
The paths look like the little streams
Though water I have none
I'm on my way to where the burning stone
Is cut into deep ditches by the sun,
What rocks for centuries have ever covered.
A jet of shining veins of ore
Where sunbeams pore upon the ground
With not a drop of moisture anywhere around.
And only in the bluish darkness of the night
I wend my way to where I can sleep tight.

Well, my younger reader, did all this draw you to our work, or did the difficulties make you turn away from it?

Why not overcome the difficulties and thus get much stronger? In Vietnam I have recently climbed very high mountains, mak-

ing my way through the jungle. It would be paltering with the truth to say that it wasn't a bit of gruelling uphill work. What the Vietnamese colleagues said later was that they were surprised how a Soviet seventy-year-old grannie could find herself fit to go up the practically inaccessible deposits the scientific and practical validity of which could be assessed only with one's own eyes. And don't you think that it is precisely in overcoming these difficulties that we find the very essence of what we are striving to achieve in life?

If what you want to understand
Is that the space is absolute and time is not,
You have to go to far-off lands
Without a mundane thought!
A moment—and the bluish smoke of Moscow region
Is on its smooth flight into the unknown,
Into the land on top of which
The clouds are like the cotton that is torn.
Winds and hurricanes can frighten us no more
With ongoing time erasing what was planned
And thousands of miles that are swallowed up before.
Are mapped out by the rivers:
The Ob, the Enisei and the Angara...
They seem to be serving breakfast...
In Moscow it is still yesterday
While we have flown into another day!

Are you ready to fly to the Far East now?

You will find a hearty welcome there, as soon as you care to fly into 'tomorrow'!

To the Reader

Mir Publishers would be grateful for your comments on the content, translation and design of this book. We would also be pleased to receive any other suggestions you may wish to make.

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Satellite and Typhoon
Eye-to-Eye
by S. Baibakov and A. Martynov

Studies of typhoons and hurricanes based on conventional tracking technologies—ground weather stations, ships, aircraft, and weather rockets—rarely turn out to be effective enough, since the time and place of typhoon origin are unpredictable. A new avenue of approach to the problems is opening up with advances in space technology.

This book presents a detailed method to explore *in situ* typhoons and hurricanes using satellites and satellite probes to deliver balloons with a payload of measuring instruments into their effective range. There is also an extensive discussion of problem areas in meteorology, oceanography, and environmental science capable of being addressed by space-borne technologies.

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by N. Yasamanov

The principal advances in geoscience are discussed in this book. Prof. N. Yasamanov tells us about the role that geology plays in human society, about the Earth's structure, origin and history. He describes the beginning of life on Earth, the distribution of natural resources over the globe and the protection connected with environment protection.

The book is intended for senior schoolchildren, teachers and all who are interested in Earth sciences; it would also be helpful for students of geological exploration in technical schools.